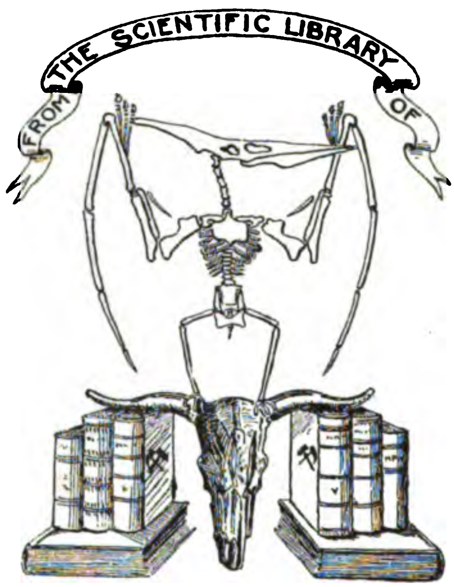

WILLIAM DILLER MATTHEW

COLLECTED MEMOIRS
of
LAWRENCE M. LAMBE

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Number

W. D. Matthew

GEOLOGICAL SURVEY OF CANADA

ROBERT BELL, M.D., D.Sc., LL.D., F.R.S.

ON TRIONYX FOVEATUS, LEIDY, AND TRIONYX VAGANS, COPE, FROM THE CRETACEOUS ROCKS OF ALBERTA

BY

LAWRENCE M. LAMBE, F.G.S., F.R.S.C.

Assistant Palaeontologist.

No. 1

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OTTAWA

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1902

Gift of [illegible]
C. D. Matthew

ON TRIONYX FOVEATUS, LEIDY, AND TRIONYX VAGANS, COPE, FROM THE CRETACEOUS ROCKS OF ALBERTA.

By Lawrence M. Lambe

(With four plates.)

During the past summer whilst engaged, on behalf of the Geological Survey, in making a collection of vertebrate remains from the Cretaceous of the Red Deer river, Alberta, to supplement the material obtained in two former years, the writer was fortunate enough to secure two almost complete carapaces of turtles, one referable to *Trionyx foveatus*, Leidy, the other to *T. vagans*, Cope. In the Red Deer river district, referred to, the remains of these two species are abundant and are found associated with a number of other species of Chelonia, of which one is *Adocus variolosus*,* Cope (sp.), remarkable alike for its size and the strikingly rugose character of the sculpture of its shell. The rocks holding these remains belong to the Belly river series of the Cretaceous brackish water deposits underlying the Pierre Fox-Hills formation, by which they are separated from the still higher Laramie series.

Trionyx foveatus† was originally described in 1860 by Leidy from small fragments of costal and sternal bones from the Judith river beds of Nebraska.

*Proceedings of the Academy of Natural Sciences of Philadelphia, vol. XXVIII, p. 257, 1876 (Cope), and Ottawa Naturalist, vol. XV, p. 63, plates iii, iv, v and vi (Lambe).

†Transactions of the American Philosophical Society, vol. XI, p. 148, pl. xi, figs. 1 and 2. Extinct Vertebrata from the Judith river and Great Lignite formations of Nebraska.

The Red Deer river specimen of *T. foveatus* consists of the carapace, in which the nuchal plate is missing, without any part of the plastron. Sternal plates, probably referable to this species, were found not far distant, but further reference will not be made to them here.

The carapace (Plate II, fig. 2) is a little less than one-fourth broader than long, and is only slightly convex. The eight costals of the left side are practically entire, but the first right costal is wanting. Five neural plates are preserved with part of another that lay principally between the first costals, its posterior end being between the front inner borders of the second costals. If this neural were as long in proportion to its breadth as the plate immediately following it, its front margin probably effected a sutural union with the nuchal plate, and its outline was presumably as is shown by the dotted lines in the figure.* Neurals two, three and four are six-sided, neural five is oblong, and neural six, lying for the most part between the sixth costals, is shield-shaped, coming to a point behind. The seventh costals are suturally united at their inner ends, where they develop a breadth sufficient to separate the eighth costals from each other. These latter are subtriangular in shape, with three convex sides. The nuchal plate was evidently small, as the lateral termination of the suture (*a* in the figure) between it and the left first costal indicates a side extension scarcely past a point in advance of the mid-length of the first costal. Small, shallow, rounded depressions mark the surface of the neurals and the inner ends of the costals. In the latter, as the distance from the neurals increases, the depressions gradually grow larger and more decided, becoming often reniform or oval, and frequently coalescing, until in the distal ends of the costals a few more or less continuous furrows are formed parallel with the outer margins of the plates. These furrows are a conspicuous feature in the sculpture; they are not so well marked on the posterior margin of the carapace, but they are well developed near the front edges of the first costals. In the neurals and inner halves of the costals there is a narrow, smooth strip devoid of sculpture bordering the sutures. The rib-heads are well developed.

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*Since the above was written some misplaced fragments have been added to the anterior end of this carapace; they reveal the fact that the first costals are in reality separated by a divided first neural. The writer wishes here to express his indebtedness to Professor Osborn and Dr. Hay, of the American Museum of Natural History, for the loan of the type of *Trionyx vagans* and the opportunity thus afforded him of making a direct comparison of the type with the Red Deer specimen.

Measurements :

	M.
Estimated length of carapace along median line ($6\frac{7}{10}$ inches)....	·170
Distance from front margin of first costal to back margin of seventh costal (slightly over $6\frac{1}{2}$ inches)........................	·167
Maximum breadth of carapace ($8\frac{4}{10}$ inches)........................	·214
Length of second neural.	·023
Maximum breadth of second neural..	·017
Thickness of fourth costal at centre near inner end............	·005
Thickness of fourth costal at centre near outer end............	·006
Thickness of eighth costal at centre........................	·005

Trionyx planus,* Owen and Bell, a British Lower Eocene species, described from the posterior half of the carapace, bears a strong general resemblance to *T. foveatus* as regards the sculpture and also in the absence in both species of the seventh and eighth neurals accompanied by a similar curtailment of the sixth neural. The strong development of the seventh costals found in the Red Deer river carapace resulting in a reduction of the eighth pair of costals may be an irregularity of growth of no specific importance.

The second species of *Trionyx* represented by an almost complete carapace is referred to *T. vagans*, Cope, first described by that authority in 1874† from 'a number of fragments of costal bones and perhaps of sternals also,' from the 'Lignite cretaceous of Colorado; near the mouth of the Big Horn river, Montana; Long lake, Nebraska; found at the last two localities by Dr. Hayden.' Later, in 1875, in 'The Vertebrata of the Cretaceous Formations of the West' the same description appears; this time with figures of two fragments of costal bones. Dr. O. P. Hay, of the American Museum of Natural History, New York, has kindly compared part of a costal plate from the Red Deer river with fragments labelled *T. vagans* by Professor Cope in the New York collections. Owing to the insufficiency of the published description and figures of this species, the writer could scarcely judge whether the Canadian specimens were or were not referable to *T. vagans*, but Dr. Hay writes that he thinks they probably are.

The carapace (Plate IV, fig. 4) is broader than long, the breadth exceeding the length by more than one-sixth and it is only moderately convex. In outline, as seen from above, it is flat behind with the sides

* Monograph of the British Reptilia of the London Clay, part I., p. 58, tab. XIXC, 849, Palæontographical Society.

†Bulletin of the United States Geological Survey of the Territories, 1874, No.2, p 27.

curving broadly to the front margin, at the centre of which there is a shallow concavity. The shell protrudes where the ribs pass outward from beneath, causing the lateral margin to be sinuous, the sinuosity being most marked toward the front in the first, second and third pairs of costal plates. Of the eight pairs of costals, the first costals are the broadest at the inner ends, whilst the fifth are the broadest distally. The seventh costals are extremely narrow throughout their length and the eighth pair is well developed. The first costals increase in breadth rather suddenly at their outer ends and are separated by a divided first neural plate. The neurals gradually decrease in breadth to the fifth, their sides being not so nearly parallel to each other as those of the corresponding plates in *T. foveatus*. The sixth and last neural is very much reduced in size and is irregularly oval in outline. Of the protruding rib-ends, all the six of the left side were secured, in a fair state of preservation, except the one belonging to the first costal and it was obtained in part. The rib-heads are well developed. In the figure, the nuchal plate is represented as entire. Of the carapace under consideration, the central part only of the nuchal plate, extending from the margin in front to the suture behind, was found, but fortunately the left end of a nuchal, of another individual of similar size, showing the left front margin and the suture between the plate and the first costal with part of the latter adherent, supplied the deficiency. The sculpture consists of a network of narrow ridges ramifying and inosculating so as to enclose small, sunken areæ of irregular shape and size, the areæ being generally wider than the ridges are broad. The frequent confluence of a varying number of areæ results in a more open pattern, the ridges at times shewing a tendency to run in parallel lines. The sculpture is not so distinctly defined near the sides of the carapace as it is toward and at the centre and anteriorly, but in the hinder part it is more decidedly rugose, the ridges being here higher and the enclosed areæ larger. Near the intercostal sutures, more particularly in the inner halves of the costal bones, the sculpture is partially effaced and consists of low, poorly defined parallel ridges at right angles to the sutures, forming a distinct border, with a maximum breadth of about ·5 centimeters. A smooth border, broadest at the sides of the carapace and narrowest in front, extends along the whole of the peripheral edge.

As regards a divided first neural in species of this genus, it is interesting to note that Lydekker in describing *T. melitensis*, from the Miocene of Malta, in 1891, (Quarterly Journal of the Geological Society, vol. XLVII, p. 37, fig. 1) mentions the occurrence in the Miocene species of a divided first neural and remarks (p. 37) that 'all the fossil species

hitherto described, of which the entire carapace is known, agree with the normal type in having but a single long neural between the first pair of costals.'

Measurements :

	M.
Length of carapace along median line (18½ inches)	·470
Maximum breadth of carapace (23$\frac{3}{16}$ inches)	·590
Breadth of first costal at inner end........	·075
Thickness of same near inner end.........	·009
Thickness of same at outer end..................	·012
Breadth of fifth costal at outer end..........	·119
Thickness of same at outer end...........	·013
Breadth at mid-length of seventh costal...........	·036
Thickness at centre of eighth costal.....	·010
Maximum breadth of neural 1.......	·056
Maximum breadth of neural 1a..............................	·039
Length of same	·043
Thickness of nuchal plate at left end	·018
Length of vertebral centrum.........................	·045

EXPLANATION OF PLATES.

PLATE I.

FIGURE 1. Upper surface of the carapace of *Trionyx foveatus*, Leidy; from the Cretaceous of Alberta. One-half natural size. The sinuous lines indicate the sutures between the bones; the dotted ones parts restored; NU, nuchal bone; N 1, 2, &c., neural bones; C 1, 2, &c., costal bones.

FIGURE 1*a*. Outline of the transverse curve of the upper surface of the carapace.

PLATE II.

FIGURE 2. Upper surface of the carapace shewn in plate I; from a photograph. Considerably over one-half the natural size.

PLATE III.

FIGURE 3. Upper surface of the carapace of *Trionyx vagans*, Cope; from the Cretaceous of Alberta. One-eighth the natural size. Lines and letters as in figure 1 of plate I.

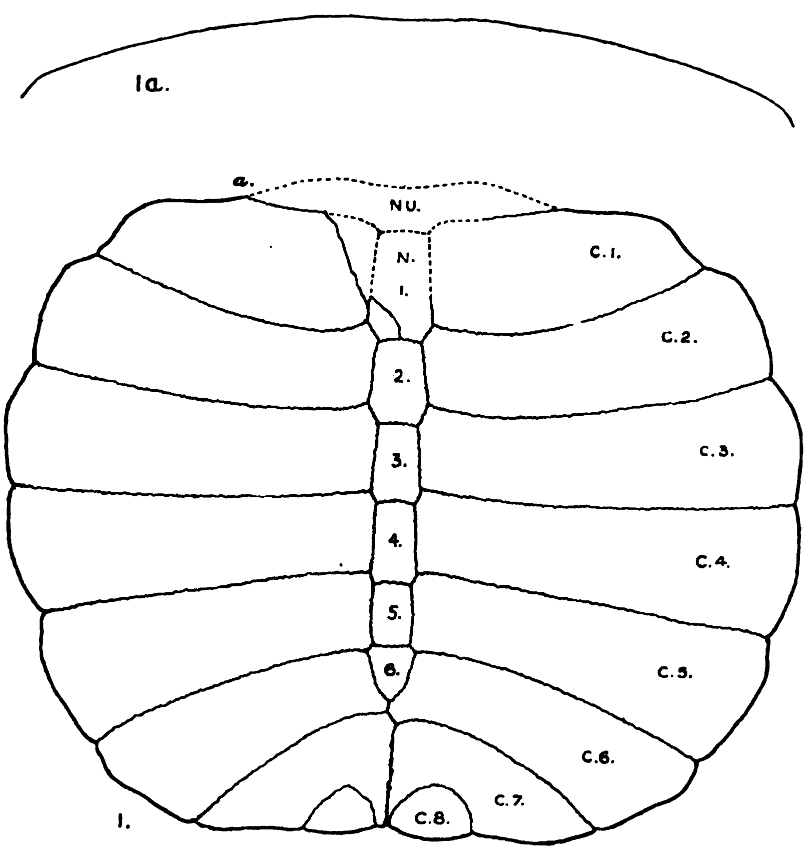
FIGURE 3*a*. Outline of the transverse curve of the upper surface of the carapace.

FIGURE 3*b*. The sculpture of part of the upper surface of the same carapace; from a photograph. Natural size.

PLATE IV.

FIGURE 4. Upper surface of the carapace shewn in plate III; from a photograph. Slightly less than one-fourth natural size.

1a.



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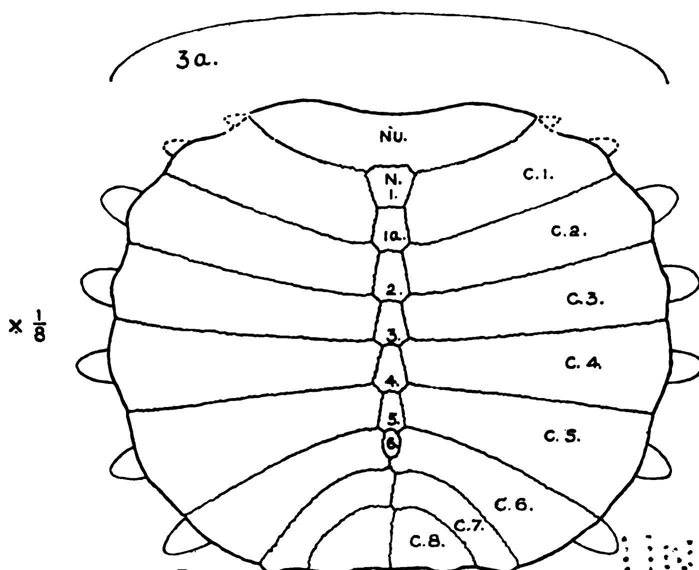
2.



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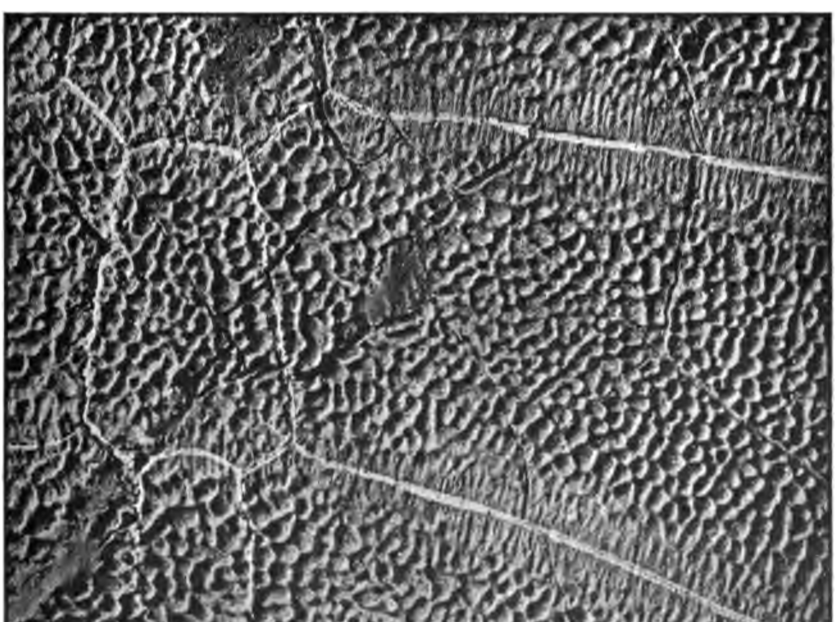
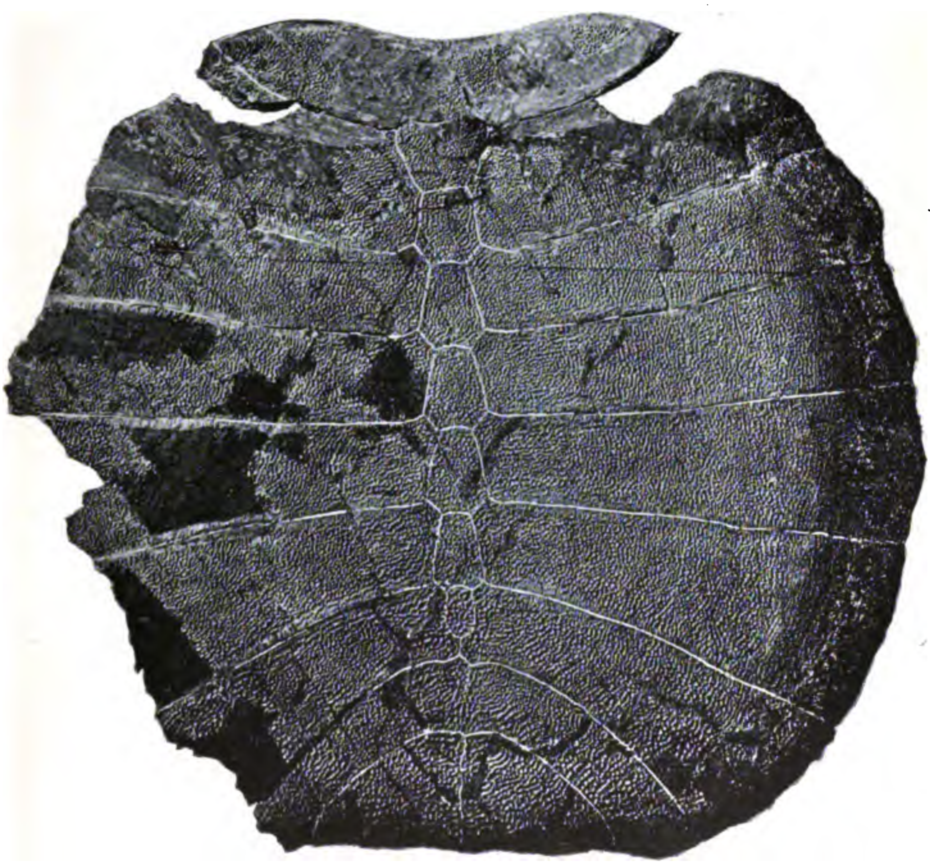


3b.



W. D. Matthew

GEOLOGICAL SURVEY OF CANADA

A. P. LOW, DEPUTY HEAD AND DIRECTOR

NOTES

ON THE

FOSSIL CORALS

COLLECTED BY MR. A. P. LOW

AT

BEECHEY ISLAND, SOUTHAMPTON ISLAND AND CAPE CHIDLEY IN 1904

No. 2

BY

LAWRENCE M. LAMBE, F.R.S.C.

(Being a reprint from Appendix to Mr. Low's Report on "The Cruise of the 'Neptune'")

OTTAWA
GOVERNMENT PRINTING BUREAU
1907

NOTES ON THE FOSSIL CORALS COLLECTED BY Mr. A. P. LOW AT BEECHEY ISLAND, SOUTHAMPTON ISLAND AND CAPE CHIDLEY, IN 1904. (BY LAWRENCE M. LAMBE, F.R.S.C.)

NOTES ON THE FOSSIL CORALS COLLECTED BY MR. A. P. LOW AT BEECHEY ISLAND, SOUTHAMPTON ISLAND AND CAPE CHIDLEY, IN 1904.

(By Lawrence M. Lambe, F.G.S., F.R.S.C.)

BEECHEY ISLAND, LANCASTER SOUND.

Acervularia austini (Salter), 1852. Sutherland's voyage*, appendix, p. ccxxx, Strephodes ? Austini, pl. 6, figs. 6, 6a.

The type specimens of this species were obtained at Cornwallis, Beechey and Griffiths islands. A number of corals in Mr. Low's collection, from Beechey island, appear to belong to this species, judging from Salter's description and figures and those of Houghton in the Journal of the Royal Dublin Society, vol. 1, 1856-57 (1858), p, 246, pl. x., figs. 2, 2a.

In Mr. Low's specimens the inner structure is fairly well shown. The larger septa pass to the centre of the corallites where they are slightly twisted, and together with the arched, rather vesicular tabulæ, form a definite central area that appears at the bottom of the cups as a more or less distinct boss. The septa (averaging from thirty to forty in number) bear arched carinæ on their sides. The corallites are slightly larger than those of *A. gracilis*** (Billings), from Grand Manitoulin island, Lake Huron (Niagara group), otherwise the specimens could with equal propriety be referred to the Lake Huron species. The size of the corallites varies in *A. austini* from about 3 to 8 mm. in diameter, in Mr. Low's specimens up to about 10 mm. across, but in *A. gracilis* the corallites seldom reach a diameter of 7 mm. If by a direct comparison it is found that Mr. Low's specimens are without doubt properly referable to *A. austini,* and if it can be shown that the size of the corallites cannot be relied on as a specific character, then *A. gracilis* may have to be regarded as identical with *A. austini*.

The specimens of corals from Beechey island are not referable to any genus with which the writer is acquainted. In these specimens the structure is revealed, by weathering at the calicular surface and in horizontal and longitudinal sections, as well as in sections obtained

* Journal of a voyage in Baffin's bay and Barrow straits in the years 1850-1851 by Peter C. Sutherland, M.D., M.R.C.S.E., 1852.

** *Strombodes gracilis*. 1865 Geological Survey of Canada, Palæozoic Fossils, vol. 1, p. 113, fig. 94, by E. Billings ; and *Acervularia gracilis*, 1900, Contributions to Canadian Palæontology, vol. IV, pt. II, pl. XIV, figs. 2, 2a, by Lawrence M. Lambe.

by rubbing down and polishing. As the writer is unable to place this coral, to his satisfaction, in any described genus, it is thought best to establish a new genus for its reception. The main generic characters are enumerated below with a brief description of the species which the writer has much pleasure in naming after Mr. Low.

Boreaster. Gen. nov.

Corallum composite, massive (or thickly incrusting), made up of intimately connected polygonal corallites communicating with each other by means of mural pores. Septa in the form of longitudinal lamellæ, twelve in number. Tabulæ simple.

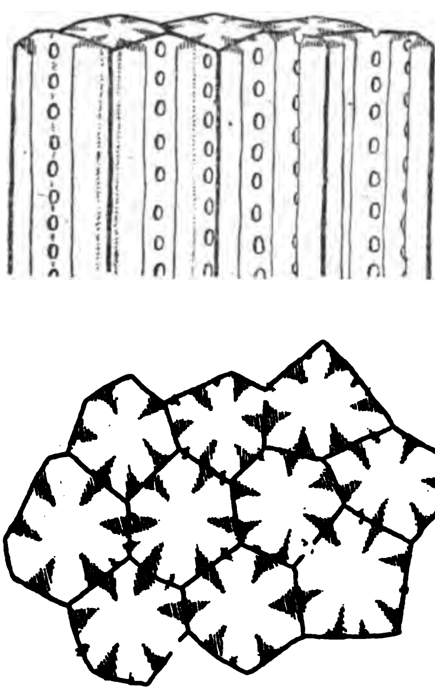
This genus resembles *Favosites* in having numerous pores in the walls of the corallites, but differs from it in the possession of lamellar septa somewhat similar to those of *Columnaria, Nyctopora* and *Lyopora.* From these three genera, however, *Boreaster* differs in having 12 septa only, of two alternating sizes, to a corallite. *Columnaria* and *Lyopora* are without mural pores. *Nyctopora* was described by Nicholson as having pores, but in well preserved specimens from the type locality, examined by the writer, mural pores were not seen; it possesses 16 septa of two orders. *Boreaster* and *Calapœcia* resemble each other in both having pores, but in the latter genus the corallites are not intimately united under any circumstances, and the septa are in the form of spine-bearing ridges.

This intesting coral may be conveniently grouped with the *Favositidæ,* as its generic affinities appear to place it close to *Calapœcia.*

Boreaster lowi. Sp. nov.

Corallum growing in irregularly shaped masses with an unevenly undulating surface; composed of small, polygonal corallites so closely united that all trace of the line of contact between contiguous walls is apparently lost. Corallites opening at right angles to the surface, averaging about ·75 mm. in diameter and generally five or six sided, as seen in transverse section, the sides of the polygons being distinctly unequal. Walls of corallites thin but less so where they bound the calyces. Septa lamellar, apparently 12 in number, of two sizes, primary and secondary, alternating, the former stout and relatively large, the latter rudimentary and observed with difficulty, especially in the calyces where the six primary septa are paramountly evident, are slightly exsert and apparently connect with the nearest and corresponding ones of contiguous corallites. Pores relatively large, oval, their greater diameter vertical, in a single longitudinal row between

each pair of primary septa so as to interrupt the continuity of the secondary septa which are greatly reduced and in transverse sections



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are only observed in places. Tabulæ not numerous, in the form of simple, flat transverse diaphragms.

The two type specimens have a maximum length of 50 and 70 mm. with a thickness or height of 25 and 30 mm. respectively.

Favosites gothlandica, Lamarck.

There are three examples of this coral, of which two show spiniform septa in the corallites. The smaller of the two specimens, in which septa are seen, is preserved with a small corallum of *Acervularia austini* in the same piece of limestone.

The horizon indicated by the first and last of the above three species of corals from Beechey island would be about that of the Niagara formation.

Streptelasma robustum, Whiteaves.

This large and well marked species, described originally from the Galena-Trenton of the Lake Winnipeg region, is represented by a number of more or less fragmentary specimens. The inner structure is well shown in transverse and longitudinal sections.

Favosites gothlandica, Lamarck.

Over forty specimens from this locality are referable to this well known species. In many of them are seen the spiniform septa, characteristic of all Silurian favosites, and distinguishing them from all Devonian forms which apparently without exception possess linguiform septa. It is possible that more than one species may be here represented. The range in size of the corallites in *F. gothlandica* has been noticed by the writer in his 'Revision of the genera and species of Canadian Palæozoic corals*,' 1899-1900, but in the present collection the fragmentary condition of most of the specimens does not admit of characters dependent on the outward form of the corallum being used with any degree of certainty.

Syringopora verticillata, Goldfuss.

A single specimen of this species was obtained at Southampton island. Its corallites average about 4 mm. in diameter and are rather lax and irregular in their growth, the result of which is that the connecting tubes are poorly developed and comparatively distant. This particular mode of growth is admirably shown in specimens, in the possession of the Survey, from the north end of Lake Timiskaming.

Halysites catenularia, L.

Represented by a small corallum, round which has grown a stromatopora. This coral exhibits the structure characteristic of the typical form of the Niagara formation, viz., moderate sized corallites, oval in transverse section with narrow tubules intervening. Four corallites are included in a space of 8 mm.

This form also occurs in the Guelph limestone of Ontario.

A second and particularly interesting specimen was obtained by Mr. Low at Southampton island. It differs from the typical form

* In this report the reader will find extended references to the structure of the majority of the species mentioned in these notes.

in having corallites of noticeably large size, and agrees in this particular with a specimen from the Guelph limestone at Durham, Ont. (J. Townsend, 1884), in the museum of the Survey. The Durham fossil has not the finer details of structure sufficiently well preserved to show the minute tabulæ of the tubules, but in Mr. Low's specimen longitudinal sections of the tubules clearly reveal the highly arched, close set tabulæ within. There are three corallites in a space of 12 mm., as in the Durham specimen, and the tubules have a width of about ·75 mm.

Plasmopora follis, M.-E. and H.

To this species is referred a small specimen showing the inner structure fairly well. The corallites vary in diameter from slightly under to a little over 1 mm., and they are mostly less than their own diameter apart with from one to three tubules. in the shortest line, between neighbouring corallites. This species is generally considered to be typical of the Niagara group.

Pycnostylus elegans, Whiteaves.

A few specimens weathered so as to show only the inside of the corallites which vary in diameter from 7 to 15 mm. An interesting feature of these specimens is the preservation of the free edges of the septa which are seen to be denticulated, about seven denticles occurring in a space of 2 mm. A re-examination of the type material reveals the presence of these denticles, although they are poorly preserved. Mr. Low's specimens are referable to the species from the Guelph limestone of Ontario with large corallites (from 13 to 17 mm. in diameter) as in the other and type species from the same horizon and district, the corallites are generally smaller (from 3 to 7 mm. in diameter). As suggested by Dr. Whiteaves in his original description, additional material with corallites of intermediate size may prove the two forms to be specifically identical.

Of the corals from Southampton island, *Streptelasma robustun.* indicates the presence of beds at this locality that belong to the same horizon as those that have been assigned to the Galena-Trenton in the Lake Winnipeg region, and similar beds exposed over a large area to the west of Hudson bay. The beds from which the other species from the same island are derived belong to higher horizons which are, on the evidence of these species, of about the same geological age as those of the Niagara and Guelph formations of Ontario.

W. D. Matthew

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Geological Survey

Museum Bulletin No. 12

GEOLOGICAL SERIES, No. 24 MAY 7, 1915

ON EOCERATOPS CANADENSIS, GEN. NOV., WITH REMARKS ON OTHER GENERA OF CRETACEOUS HORNED DINOSAURS

No 3

by

Lawrence M. Lambe

OTTAWA
Government Printing Bureau
1915

No. 1510

May 7, 1915.

Canada
Geological Survey
Museum Bulletin No. 12.

GEOLOGICAL SERIES, No. 24.

On Eoceratops canadensis, gen. nov., with Remarks on Other Genera of Cretaceous Horned Dinosaurs.

BY LAWRENCE M. LAMBE.

The above species was established in 1902[1] on parts of the skull of one individual collected by the writer in the Belly River formation on the east side of Red Deer river, Alberta, a short distance below the mouth of Berry creek, during the summer of 1901. In the original description the species was referred to the genus Monoclonius, Cope.

The type material consists of the right squamosal (Cat. No. 1254a), the right posterior lateral extension of the parietal (Cat. No. 1254b), the right postfrontal and prefrontal with the supraorbital horn-core rising from the former bone (Cat. No. 1254d), the right nasal including the right half of the nasal horn-core (Cat. No. 1254c), the left dentary without teeth (Cat. No. 1254e), and an anterior dorsal vertebra (Cat. No. 1254).

More detailed descriptions, with figures, of the squamosal and the posterior parietal bar were published in 1904[2].

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[1] Geological Survey, Canada; Contr. to Can. Palæont., Vol. III (quarto), Plate II, pp. 63-66, figures 18 and 19, Plate XVII, figures 3 and 4, and Plate XVIII, figures 1-7.

[2] Trans. Royal Soc. of Canada, Vol. X, second series, pp. 7-9, Plate II, figures 4-7c; and Ottawa Naturalist, Vol. XVIII, p. 83, Plate II, figures 4-7.

The above type material is regarded as representing an undescribed generic form of Ceratopsia to which the name Eoceratops is now given.

Eoceratops appears to be a generalized type with an occipital crest or neck-frill resembling that of Triceratops in the broad triangular squamosal but differing very decidedly therefrom in the presence of long fontanelles. An approach to Triceratops is also found in the enlarged supraorbital horn-core and in the formation and position of the small, forwardly directed nasal horn-core.

It is thought, as the name for the genus suggests, that Eoceratops was a form ancestral to Triceratops, representing an evolutionary stage of the Ceratopsia leading to the later and culminating types (Triceratops and Diceratops) with immense brow-horns.

The characters of Eoceratops may be summarized as follows: skull small, short, compact; supraorbital horn-core moderately large, slender, overhanging the orbit, circular in cross section, tapering to a point and directed upward, and slightly inward and backward above; nasal abbreviated and deep; nasal horn-core short, contributed to by the nasals and two separate, anterior ossifications; crest or neck-frill slightly longer than half the total length of the head; squamosal broadly triangular, longer than broad, with a smooth, undulating outer border, without epoccipitals, forming the greater part of the crest laterally; fenestræ of the crest long, enclosed without by the squamosal, and behind by a slender parietal bar which passes forward beneath the inner posterior border of the squamosal; dentary robust, with about twenty-five vertical series of teeth.

In the restoration outline of the skull given in Plate I, the parts of the one individual constituting the type material are shown by continuous lines; the parts restored are in broken outline. A right maxilla (Cat. No. 285) thought to belong to Eoceratops has been used in the restoration of the skull. It was found separately about 3 miles below the mouth of Berry creek and cannot be positively referred to this species. From the elements represented the length of the skull is approximately obtainable, the unrepresented parts necessary for the determin-

ation of its exact length being the premaxilla, the rostral bone, and the median portion of the neck-frill. The restored outline indicates a short, heavily built head, in which the total depth from the upper surface between the supraorbital horn-cores to the lower margin of the dentary, is slightly over one-third of the length from the front edge of the rostral bone to the back border of the frill.

Eoceratops thus appears to have had a short skull, compact and deep in front, and tapering behind as seen in side view. The lower jaw is robust, the nasal bones are remarkably deep, and the supraorbital horn-cores are large in comparison with the inconspicuous nasal horn-core (Plate I). This compactness of the anterior half of the skull with great depth is also found in Brachyceratops, a form in which the nasal horn was the principal weapon of defence. In comparison with Eoceratops the later Triceratops has lengthened the face and added greatly to the size of the supraorbital horn-cores to the neglect of the nasal horn. In Diceratops with the enlargement of the brow-horns there is the concomitant non-development of the nasal one.

The supraorbital horn-core rises from above the orbit, so as to overhang the latter's anterior half, its front convexity at mid-height being almost directly above the anterior surface of the rim of the orbital opening. The horn-core tapers to a point and throughout its length is circular in cross section, except near the base where there is a very slight flattening above the orbit and a feeble lateral compression on the antero-exterior face causing the fore and aft diameter to somewhat exceed the transverse one. In shape, without considering its direction of growth from the head, it very much resembles that of a modern bison, but it is shorter, tapers more rapidly, and is less curved than the average horn-core in the adult mammal.

The postfrontal (Plate IX, figure 1) is of irregular shape, broad behind and narrow in front with the base of the supraorbital horn-core rising from it slightly in advance of its mid-length. The surface slopes gently backward and inward from the base of the horn-core in continuation of the concave curve of the same. Postero-externally it is bent downward with a decided angulation to form a nearly vertical plate of some extent,

the foremost part of which constitutes the hinder border of the orbital opening. In advance of its midlength, in line with the centre of the horn-base the bone is much reduced in breadth by the upper curve of the orbital opening externally, and by an emargination of its border (postfrontal fontanelle) internally. The breadth of the bone is here occupied almost entirely by the base of the horn-core which externally curved down into the orbit. From its inner side the edge of the bone runs obliquely forward and outward close under the steep inner anterior face of the horn-base. Anteriorly the bone curves concavely forward as a narrow spur to meet the nasal. Antero-externally it extends outward conspicuously as the upper front part of the orbital rim acting as a buttress to the horn-base, and no doubt in life serving as a protection to the eye. Elsewhere, above and behind, the rim of the orbital opening rounds into the surrounding bone without any protrusion.

The postfrontal ends postero-laterally beneath in a rather straight suture which underlaps the jugal. This suture reaches the orbital rim low down in the orbit. Behind, the suture for the squamosal passes upward onto the upper surface in the form of a deep groove into which the edge of the squamosal fits. At its upper end this groove enlarges into a pit or socket for the reception of a forwardly directed peg from the squamosal. Posteriorly the bone apparently reached the edge of the supratemporal fossa between the squamosal and the median portion of the neck-frill as in Styracosaurus, Centrosaurus, and Chasmosaurus. Its inner edge forms a concave curve cutting into the slope descending from the horn-base. This edge is the lateral boundary of the postfrontal fontanelle in advance of the suture between the postfrontal and the anterior end of the median frill element (coössified parietals) so clearly preserved in the type of Styracosaurus. In front the line of contact with the prefrontal runs outward and forward and then obliquely inward to the nasal with which latter element the postfrontal was in sutural contact for a short distance at right angles to the longitudinal axis of the skull.

The prefrontal (Plate IX, figure 1) is irregularly five sided. Its upper surface is somewhat concave sloping slightly downward

to the front and toward the outer side. This bone met its fellow toward the front for a short distance in the midline of the skull. Outwardly on two of its sides it was bounded by the postfrontal. The suture for the nasal is shown in the specimen as a transverse groove in its front border.

The frontal is not preserved, but its size and position are indicated by the inner posterior edge of the prefrontal (Plate IX, figure 1). It was, therefore, triangular in outline, and with its fellow, ran forward for some distance between the prefrontals. It appears to have been relatively smaller than the same bone in Centrosaurus (Plate IX, figure 2) and Styracosaurus and, as in these two genera, the posterior edge of the pair no doubt formed the anterior margin of the postfrontal fontanelle.

The lachrymal is not preserved in the type material but it evidently formed the lower anterior part of the orbital rim, as a small roughened sutural surface (Plate I) at the lower limit of the postfrontal part of the rim, in line with the centre of the orbital opening, marks its entry into the formation of the rim. The lachrymal carries downward the prominence given to the rim by the postfrontal. Anterior to this small roughened surface the remainder of the lachrymo-postfrontal suture is not clearly indicated. From our knowledge, however, of the exact shape and position of the lachrymal in Centrosaurus it is probable that this bone in Eoceratops would have somewhat similar proportions and lie along the lower edge of the postfrontal reaching the nasal in front.

The nasal (Plate I) is short, very deep, and thin through from the exterior to the interior surface. Inferiorly in front a narrow, stout process descends to articulate with the premaxilla, and posteriorly there is a broad thin extension passing downward to meet the posterior ascending process of the premaxilla. Between these processes the lower border is deeply emarginate and forms the upper half of the nasal opening. The outer surface is flatly convex from above downward. The bone thins near the hinder border and flares outward to form a suture overlapping the lachrymal and postfrontal, and fitting into the grooved anterior edge of the prefontal.

The nasal meets its fellow in a flat, vertical, triangular surface of contact which extends, with increasing depth, from the prefrontal suture to nearly the full depth of the bone in front. This large sutural surface occupies more than one-half of the inner surface of the bone and must have given great strength to the anterior nasal region. Behind this extent of contact the inner surface of the bone is excavated and the bone is reduced in thickness. The anterior descending process displays a well defined flat, oval surface on its inner front face for its sutural union with the upper limb of the premaxilla. The posterior descending extension is divided into two unequal parts by a deep groove at its lower end to receive the ascending posterior limb of the premaxilla. Anteriorly and facing obliquely outward and forward, there is a shallowly concave sutural surface of crescentic outline for the reception of a separate bone which, with its mate and the anterior end of the nasals, formed the nasal horn-core. This separate ossification is transversely compressed, higher than long, pointed above, thickest at the centre and thin toward the hinder and lower margin. Its outer surface is convex, flush behind with that of the nasal, and rounds forward and inward to the median line. Its inner surface shows that it met its fellow in a vertical surface in the median line. Its outline is convexly curved behind and below, and almost vertical in front. The nasal rises upward and extends over the ossification nearly as far forward as the front face of the latter which at its lower end is considerably in advance of the proximal end of the anterior descending nasal process.

The nasal horn-core of Eoceratops is thus seen to be formed by the nasals with the assistance of two separate bones, which may be called the epinasals, anterior to the nasals, the median vertical plane of contact between the two pairs of bones dividing the horn-core into two equal parts. This vertical, longitudinal division of the nasal horn-core is seen in the type specimen of *Brachyceratops dawsoni* (Plate VI, figure 3), and has had special attention drawn to it by Gilmore in his description of *B. montanensis*. In the type specimens of *E. canadensis* and *B. montanensis* the vertical division of the horn-core is continuous due no doubt to juvenility; with greater age coössification would be expected.

In the type specimen of *B. dawsoni* the large backwardly curved nasal horn-core exhibits this division in the median line at its base and for a short distance upward into the horn-core, but above this all trace of it is lost. Also in this particular horn-core (*B. dawsoni*) there is a very definite demarcation traceable between the anterior ossifications (epinasals) and the nasals (Plate X, figure 4). In the growth of the ceratopsian nasal horn-core an early union took place between the epinasal bones and between them and the nasals.

In Mr. Gilmore's paper on *B. montanensis*, in figure 1A on page 4, a definite curved groove is shown, in the anterior part of the nasal horn-core at its mid-height, which is strongly suggestive of the upper boundary of the epinasal ossification. If this groove represents what remains of the upper part of the suture between the ossification and the nasal the union of the lower portion of the former bone with the nasal had, judging from the figure, already taken place without leaving a trace of the lower portion of the suture (Plate X, figure 3).

Attention has already been drawn to the extension of the nasal forward over the epinasal in the type of Eoceratops which evidently represents an individual not fully adult. It is probable that in the growth of the ceratopsian nasal horn-core the nasals, with increasing age in the individual, contributed an increasing share to the formation of the horn-core, the epinasals remaining of relatively small size and acting apparently as an anterior basal support to the nasal contribution. In comparing the relative proportions of the nasal and epinasal bones in the horn-core of *E. canadensis* and of *B. montanensis* (Plate X), keeping in mind differences that may be due to individual age in distinct genera, it is seen that in the type of the latter species the nasal contribution to the horn-core is much larger than in the former. Also in the nasal horn-core of *B. dawsoni* (Plate X) the proportion supplied by the nasals is preponderant, the epinasals entering into the formation of the horn-core only as small anterior buttresses.

The squamosal (Plate I) has been already described in some detail in two papers published in 1904.[1] It is irregularly tri-

[1] Op. cit., p. 1.

angular and longer than broad, its greatest length being about one and a half times the maximum breadth. In lateral outline the outer free border forms a sinuous convex curve to the posterior pointed end, and the inner border a concave one to the same termination. The front edge, constituting the base of the triangle, displays, in succession from below upward, the posterior margin of a deep quadrato-jugal notch, the hinder half of a rather large lateral temporal fossa, a short suture for contact with the jugal which overlapped it, and a long one for the postfrontal.

Both the outer and inner surfaces of the bone are remarkably smooth. A few inconspicuous vascular grooves occur on the outer surface back of the suture for the jugal. Superiorly in front the bone is bent inward about at right angles to the general plane of its outer surface, forming a strong angulation which descends backward from the postfrontal suture in continuation of the postfrontal angulation behind the horn-core. The bone is here thin and comes to a sharp inner edge, which constitutes the outer boundary above of the supratemporal fossa. The lower free border flares outward somewhat causing the general surface of the bone to be concave in a longitudinal direction, but it is difficult to say whether this is normal or accentuated by pressure.

The coalesced parietal portion of the neck-frill is known only from the slender postero-lateral bar by means of which a union was effected with the squamosal. This parietal bar (Plate I) passed forward beneath the inner border of the squamosal, which was grooved to receive it, to a point slightly in advance of the latter's length. It is of nearly the same breadth for the greater part of its length, tapering slightly in front for a short distance before it apparently terminates. That part of the bar which underlies the squamosal is triangular in cross section. Its upper surface is flat where it comes in contact with the squamosal, but beneath there is a ridge which passes with decreasing prominence from the middle of the lower anterior surface obliquely backward to the inner edge. Behind the squamosal, in its free part, the bar is lenticular in cross section, curves slightly inward, and gives evidence, where it is broken off, of having expanded horizontally but to what extent is not

known. On its outer free border there is a convexity which is a backward continuation of the series of undulations of the free border of the squamosal. Also, behind the squamosal, the bar has a slight axial twist which would bring its upper surface into greater conformity with the general plane of the median portion of the neck frill.

The form of the back and median portions of the frill and the size and shape of the fontanelles must for the present remain conjectural. That the openings in the frill were long in a fore and aft direction is indicated by the squamosal and the portion of the parietal bar remaining.

The frill opening on either side was not altogether within the parietal, as in all other known forms of the Ceratopsia in which fontanelles were present, but was bounded on the outer side, for the greater part of its length, by the squamosal and to a limited extent postero-laterally by the parietal bar. In the specimen the beginning of the inward curve of the bar, with an increased breadth, is shown immediately in advance of the break and suggests an outline to the posterior border of the frill and the median portion between the fontanelles as indicated in Plate II, figure 2. The undulations of the outer border of the squamosal continued backward by the parietal bar suggests a sinuous posterior border to the frill and it is probable that the median parietal portion between the fontanelles was of considerable breadth as an offset to any weakness in the frill occasioned by the tenuity and shortness of the lateral bar beneath the squamosal.

The lower jaw (Plate I) is represented in the type material by the dentary, a robust bone whose maximum length is slightly over three times its depth at midlength. The height of the top of the coronoid process above the lower border is nearly equal to one-half the length of the bone. In comparison with the larger dentary of Chasmosaurus (Plate VIII) it is proportionately more robust. Apart from having lost the teeth, the specimen is in a good state of preservation displaying very distinctly the surfaces for the articulation of the predentary, the splenial, the angular, and the surangular. There were about twenty-five alveoli for the teeth.

As already stated this species was originally referred by the writer in 1902 to the genus Monoclonius, Cope. In 1907 Mr. J. B. Hatcher, in his monograph on the Ceratopsia assigned it to Ceratops, Marsh. In the writer's opinion neither of these genera is at present on a sound basis and available for use.

The genus Ceratops, Marsh (type species *C. montanus*) is based on a pair of supraorbital horn-cores and an occipital condyle belonging to one individual from the Judith River beds on Cow creek, a tributary of Missouri river in Montana, U.S.A. No other parts of the skeleton are known. These horn-cores curve "strongly outward and slightly forward" (Ceratopsia monograph, page 172) the concave curve being on the outer side of the core. In Eoceratops the opposite is the case, the horn-core curving inward and backward with the concave curve on the inner side.

The validity of the genus Ceratops rests mainly on the shape of a pair of supraorbital horn-cores, and if any reliance can be placed on the position, size, and shape of horn-cores in the Ceratopsidæ as an aid to differentiation in that family then the supraorbital horn-cores of *Eoceratops canadensis* clearly indicate its distinctness from Ceratops, without reference to other parts of the skull which in the case of Ceratops are not at present available. Such a decided dissimilarity in the shape of the brow-horns suggests equally great differences, most probably of generic value, elsewhere in the skull. From our present knowledge of the horn-cores of the Ceratopsidæ their curvature, or the direction of their growth, is constant in any species. In individuals of the same species there is remarkably little variation in the curvature or direction of growth of both the supraorbital and nasal horn-cores. This is seen in Styracosaurus, Centrosaurus, Eoceratops, Chasmosaurus, and Triceratops, and is probably true of all the genera. Differences of size occur, no doubt due to age and possibly to sex, but apparently the growth of a horn-core is in a definite direction, forward, upward, or backward, and also with inward or outward curvature in the case of brow-horns, according to the genus and species to which the individual belongs.

The genus Ceratops, Marsh, is defined in Hatcher's memoir on "The Ceratopsia," page 100, as follows: "The present genus may be distinguished from *Monoclonius*, Cope, based on material from the same beds in Montana, by the greater development of the supraorbital horn-cores, the longer and narrower squamosals, the enlarged fontanelles, by which the parietals are reduced to slender median and lateral bars. The nasal horn-cores are very probably quite different also in the two genera, though we cannot as yet be certain as to their character in *Ceratops*. From our present knowledge of the skull of *Ceratops* it seems to have been a precursor of *Torosaurus*, Marsh, while *Monoclonius*, Cope, appears to have been ancestral to *Triceratops*, Marsh."

As the material on which *Ceratops montanus*, the type of the genus, is based consists of a pair of supraorbital horn-cores and an occipital condyle, no other parts of the skull (and nothing of the rest of the skeleton) being known, the above characters assigned to the squamosals, and the parietals and their openings are hypothetical. Mr. Hatcher in his monograph, page 97, expressed his conviction as to the generic identity of *Eoceratops* (*Monoclonius*) *canadensis* and *Chasmosaurus* (*Monoclonius*) *belli* with *Ceratops montanus* and no doubt it was this view which led him to assign characters to Ceratops for which there was no warrant in the generic type.

In 1897 the writer collected in the Belly River formation, Red Deer river, Alberta, a left supraorbital horn-core (Cat. No. 254) which more nearly resembles those of *Ceratops montanus* in its general shape, and forward and outward curvature, than those of any other ceratopsian of which he has any knowledge.

At present the characters of the genus Ceratops, Marsh, are not sufficiently definable and it will be necessary to await the discovery of further material before its relationship to known members of the Ceratopsia can be satisfactorily determined.

In *Eoceratops canadensis*, of which the principal diagnostic parts of the skull are known from excellently preserved material, the brow-horns are very different in shape and curvature from those of *Ceratops montanus* and it is reasonable to suppose that the skull of the latter when found will exhibit strong distinctive characters.

Also in *Chasmosaurus belli* (Plate VIII), of which the entire skull (including the lower jaw) is known, the brow-horns differ entirely from those of Ceratops.

The genus Monoclonius, Cope, with *M. crassus* as the type species, is unfortunately also in a very unsatisfactory state. According to Hatcher (Monograph on the Ceratopsia, 1907, page 73) the actual type material described by Cope from the Judith River district, Montana, U.S.A., was apparently "of a composite nature and pertained to two or more individuals."

The genus and species were originally defined by Cope as follows:—

"Char. gen.—Teeth with obliquely truncate face and distinct root, which is grooved for the successional tooth on the front. No external cementum layer, caudal vertebræ biconcave, and brim narrow. Fore limbs large and massive."

"The teeth of this genus resemble those of *Hadrosaurus*, and like them are replaced from the "front," an arrangement which precludes the possibility of more than one series of teeth being in functional use at one time. The robust fore limbs and elongate ilium distinguish[1] Monoclonius from Hadrosaurus. From Trachodon it differs in the absence of the rough cementum layer on the back of the tooth."

"*Char. specif.*—The faces of the teeth are acuminate, oval in form and are divided by an elevated keel, which is median above, but turns to one side at the base. Margin, crenate, the grooves extending more or less on the crown 'back,' which is otherwise smooth."

"Sacrum with ten vertebræ, the last centrum much compressed, the diapophyses extending horizontally from the neural arch above, and connected by a vertical lamina with the iliac supports; length 27·33 inches. The bones of the limbs are robust, the hinder the longer, but not so much so as in some other genera. Length of femur 22 inches; width proximally, 7·4 inches; distally 6 inches. Length of tibia 20 inches; greatest diameter, proximally, 8 inches; distally, 7·25 inches. The

[1] In the original description the word *Monoclonius* was by mistake printed *Diclonius*.

three anterior dorsal vertebræ are coössified, and the first exhibits a deep cup for articulation with the preceding vertebra. The episternum is a T-shaped bone, thin and keeled on the median line below. Length of transverse portion 21 inches."

As already pointed out by Hatcher a number of errors were included in the above definition. The teeth described are those of a trachodont, the supposed episternum proved to be the parietal portion of a frill as recognized by Cope in later descriptions, and the three vertebræ described as being anterior dorsals were found to be cervicals.

The type material described and figured by Hatcher in his monograph includes besides the coössified parietals, a sacrum, and cervical, dorsal, and caudal vertebræ. Limb bones, a scapula and coracoid, an ilium, and an ischium are also figured and described as pertaining to *M. crassus*, and a left postfrontal bone bearing a horn-core, mentioned by Cope, is referred with a query to the same species. Hatcher was of the opinion (Monograph, page 76) that the parietals, the postfrontal, and the sacrum pertained to three different individuals.

That the parietals and the remainder of the above-mentioned material, belong to the same species or even the same genus is doubtful.

In comparing the parietals of Monoclonius with those of the wonderfully preserved skulls of the horned dinosaurs from Alberta a general resemblance to both Centrosaurus and Styracosaurus is apparent.

The parietal portion of the frill of *M. crassus* appears to be a much worn or weathered specimen, judging from the original figure in the American Naturalist, Vol. XXIII, 1889, and from the seemingly more exact one in Hatcher's monograph. In general proportions it bears some resemblance to the same part of the frill in Centrosaurus if the fontanelles are as large as they are suggested to be in the above figures. If, on the other hand, the fontanelles of *crassus* were of less ample proportions than indicated in these figures, parietals of Styracosaurus, which had been subjected to severe weathering after the large posterior bony outgrowths had been broken off close to their base, would have much the appearance of the frill specimen of *M. crassus*.

As regards the supraorbital horn-core doubtfully assigned to *M. crassus* its similarity in form to that of *Brachyceratops montanensis*,[1] Gilmore is noteworthy. This "striking similarity" has been remarked on by Gilmore (page 10) who suggests a possible identity with his genus.

Owing to the imperfections of the parietals of *M. crassus* and the doubt regarding the proper association of the short brow-horn and the rest of the described material with this part of the frill, it is clear that the genus Monoclonius rests on an uncertain basis and is in need of further elucidation.

If the main characters of the skull of *Ceratops montanus* and *Monoclonius crassus* are to be made known more comprehensive material must be forthcoming, preferably from the Judith River district in Montana. The above two genera are, in the writer's opinion, not sufficiently defined for use at the present time. In the case of Ceratops there is a paucity of material inadequate in full diagnostic characters. With Monoclonius its non-employment as a generic term is considered advisable on account of the composite nature of the material described which lacks data both as regards localities and the association of the skeletal elements in the field.

Relying on the characters of the skull, the horned-dinosaurs appear to fall into three natural groups or subfamilies which are derived through separate lines of descent from one or more ancestral forms still undiscovered. These three groups are as follows: (a) Eoceratops of the Belly River formation leading to the later Triceratops and Diceratops; (b) Centrosaurus, Styracosaurus, and Brachyceratops, an apparently natural group of which the members are all from the Belly River formation and have no known descendants; and (c) Chasmosaurus of the Belly River formation ancestral to Torosaurus.

The main characteristics of the horn-cores and neck frill in these groups appear to be as follows:—

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[1] Smithsonian Miscellaneous Collections, 1914, Vol. 63, No. 3; A new Ceratopsian Dinosaur from the Upper Cretaceous of Montana with note on Hypacrosaurus, pp. 1-10, Plates 1 and 2, and text figures.

Eoceratops to Triceratops. (Plates II and V.)

Large brow-horn increasing in size.
Nasal horn persistently small.
Squamosal broadly triangular.
Parietal fontanelle disappearing (closing).

Centrosaurus, Styracosaurus, and *Brachyceratops.* (Plates III and VI.)

Brow-horn persistently small.
Nasal horn persistently large.
Squamosal continuing small.
Parietal fontanelle diminishing.

Chasmosaurus to *Torosaurus.* (Plates IV and VII.)

Brow-horn increasing.
Nasal horn decreasing.
Squamosal lengthening.
Parietal fontanelle diminishing.

The more salient characters of the skull in the best known genera of horned dinosaurs may be briefly tabulated as follows:—

	Supraorbital horn-core	Nasal horn-core	Squamosal	Parietals	Fenestræ of neck-frill
Eoceratops	Of moderate size directed upward, slender, circular in cross-section, curving inward and slightly backward in its upper part.	Very short, pointing upward and forward, laterally compressed, arising from the anterior end of the nasals, and formed by the nasals and two separate, epinasal ossifications.	Triangular, longer than broad, outer border scalloped, without epoccipitals.	Central portion unknown. Postero-laterally consisting of a forwardly directed slender prolongation beneath the squamosal. Without epoccipitals.	Apparently long: width unknown. Enclosed behind by the parietal, and without by the squamosal principally.
Triceratops	Large, directed upward, forward, and generally outward, circular in cross-section.	Small, rising anteriorly from the nasals, pointing forward and upward.	Triangular, longer than broad, outer border scalloped, with epoccipitals.	Completely filling the space between the squamosals. With epoccipitals.	No opening.
Diceratops	As in Triceratops but more upright.	No horn-core.	Of the general type of Triceratops.	As in Triceratops.	No opening.
Centrosaurus	Varying from a roughened boss to short, stout, curving slightly backward.	Of moderate length, stout, curving forward, broadly oval in cross-section with the greater diameter fore and aft, placed well back on nasals.	Short, longer than broad, with a scalloped outer free border, with epoccipitals.	Broadly expanding behind the squamosals. Largest outgrowths from the hinder portion directed forward over the fenestræ. With epoccipitals.	Large, widely oval, surrounded by the parietal.

Styracosaurus	Incipient: its position indicated by a small concave surface.	Very large, uprightly tapering, oval in cross-section with the greater diameter fore and aft. Set well back on the nasals.	Short, irregularly four-sided, nearly as broad as long, outer margin scalloped: no epoccipitals.	Broadly expanding behind the squamosals. Outgrowths directed backward from the posterior bar. Without epoccipitals.	Of moderate size, oval, within the parietal.
Brachyceratops	Varying from incipient to small.	Enlarged, curving backward, laterally compressed.	Short, with undulating free border, without epoccipitals.	Expanding behind the squamosals; becoming platelike. Margin scalloped without epoccipitals.	If present, small and oval, within the parietal.
Chasmosaurus	Stout, short, upright, flattened on the outer surface.	Rather short, stout, curving backward, oval in cross-section.	Very long, roughly, triangular, more than three times as long as broad, outer margin scalloped and bearing epoccipitals.	Between the squamosals in the form of a slender triangular frame with a longitudinal median bar. With epoccipitals posterolaterally.	Very large, subtriangular, within the parietal.
Torosaurus	Large, directed well forward and outward, laterally compressed, ovate in cross section.	Short, broad at the base, sharp above, pointing forward and upward.	Very long and narrow, outer anterior border slightly undulating; no epoccipitals.	Between the squamosals; less slender and more plate-like than in Chasmosaurus. Without epoccipitals.	Large, circular, within the parietal.

It is considered that the species described by Cope under the name *Monoclonius sphenocerus* is allied to *Styracosaurus albertensis* and should probably be placed in the latter genus of which the Red Deer River species is the type.

As regards the lately established genus Brachyceratops of Gilmore, based on the skull of a young individual from the "Upper Cretaceous" of Montana, the writer is of the opinion that it includes the species from the Belly River formation, Alberta, originally described by him in 1902 under the name *Monoclonius dawsoni.*

In the three lines of descent through the Eoceratops, Centrosaurus, and Chasmosaurus groups, salient characters are seen in the brow-horns, the nose-horns, and the neck frill. As regards the frill, a persistent attempt is seen in all three groups to enlarge and strengthen it and to render it a more efficient means of defence by covering more of the neck and shoulders.

In the Eoceratops group greater strength was attained by the enlargement of the squamosals and the closing of the fenestræ (Plate II), resulting in Triceratops and Diceratops in a larger, more compact, and heavier covering to the neck and shoulders.

In the Centrosaurus group a larger frill surface is attained by an increase in the size of the parietal portion which expands *behind* the squamosals, these latter remaining small (Plate III). In Centrosaurus and Styracosaurus, particularly in the latter, an increased surface is gained by the addition of bony outgrowths which, while not adding to the compactness of the frill, may have served a good purpose as defensive weapons or at least as an aid to the assumption of a more alarming aspect. The fenestræ are smallest, if they have not altogether disappeared, in Brachyceratops.

In the third group, Chasmosaurus leading to Torosaurus (Plate IV), the parietal part of the frill lies not so much behind as *between* the greatly lengthened squamosals. The open framework of the older form (Chasmosaurus) is succeeded by a stronger median expansion with comparatively small openings (Torosaurus.)

A final result is reached in the Eoceratops and Chasmosaurus groups in a neck-frill of increased compactness, strength, and resisting power.

The genera included in the Centrosaurus group are all from the Belly River formation so that this group does not furnish a representative from the higher horizon in the Cretaceous in which Triceratops and Torosaurus occur as culminating types of their respective groups. This later form, if such an one existed, would probably furnish additional evidence of the attainment of somewhat similar results through different evolutionary stages.

The ancestral type of ceratopsian, presumably belonging to early Cretaceous or Jurassic times, from which the Belly River Cretaceous horned-dinosaurs descended, had, in all likelihood, a poorly developed neck-frill contributed to by small squamosals and a slender parietal framework which together enclosed fenestræ of comparatively large size (Plate II). This frill may have resembled in a general way the somewhat similarly placed, but differently constructed backward prolongation of the skull of the living *Chamaeleon vulgaris*.

It is thus seen that distinctive characters are found in the neck-frill in these three groups of horned dinosaurs. With these are linked other definite characters pertaining to the brow and nose-horns as already tabulated.

In the Eoceratops group there is an increase in the size of the brow-horns, with a continuance of a small nasal horn, and broadly triangular squamosals (Plate V).

The new genus[1] Anchiceratops of Brown founded on the posterior half of a skull from the Edmonton formation on Red Deer river, Alberta, belongs apparently to the Eoceratops group. In this genus the brow-horns are large, the squamosals are broadly triangular and of moderate length, and the frill-openings are reduced in size. In the Ceratopsia a well developed nasal horn-core accompanies small supraorbital horn-cores, and when these latter are large the former is reduced, accordingly the nasal horn-core of *Anchiceratops ornatus*, the type and only

[1] Bull. Amer. Mus. Nat. Hist., Vol. XXXIII, art. XXXIII, pp. 539-548.

known species of the genus, when discovered will most probably prove to be of small size. The characters of Anchiceratops, as at present known, seem to assign it to a position between Eoceratops and Triceratops, an evolutionary stage in accord with the position of the Edmonton formation intermediate to the earlier Belly River beds and the later Lance formation.

The members of the second group (Centrosaurus, etc.) have small brow-horns, a large nose-horn, and parietals expanded behind small squamosals (Plate VI). While in this group the nasal horn is large, its shape is distinctive in the three known genera composing the group. Thus, in Centrosaurus the nasal horn curves forward, in Styracosaurus it is straight and points upward, in Brachyceratops it curves backward.

In the two genera forming the third group there is a striking increase in the size of the brow-horns, a decrease in size in the nasal horn, and a development of very long, narrow squamosals (Plate VII).

The above three groups or subfamilies of the horned dinosaurs, which may be named the Centrosaurinæ, the Eoceratopsinæ and the Chasmosaurinæ from the most primitive member of each group respectively, occur in the Belly River formation and later Cretaceous as follows:—

Ancestral Type or Types
(undiscovered)

Horizon	Centrosaurus group	Eoceratops group	Chasmosaurus group
Belly River (Judith River)	Centrosaurus Styracosaurus Brachyceratops	Eoceratops	Chasmosaurus
Laramie (Lance Creek beds)		Triceratops	Torosaurus

Reference may here be made to the opinion expressed by Mr. Brown in a recent paper that *Centrosaurus apertus* is a synonym of *Brachyceratops*[1] *dawsoni*.

The known characters of *B. dawsoni*—large backwardly curved nasal horn-core, incipient supraorbital horn-cores (as in Styracosaurus), small squamosals, a smooth undulating free border to the frill without epoccipitals, and greatly reduced openings in the frill, if indeed they were present at all—are in marked contrast to and greatly at variance with the fully known ones of Centrosaurus a genus established by the writer eleven years ago[2] for the reception of a well preserved neck-frill discovered by him in 1901 in the Belly River beds of Red Deer river about one mile below the mouth of Berry creek. Additional Centrosaurus material in the possession of the Geological Survey, from the same locality and horizon, including skulls of which one has the lower jaw in place (Plate VI, figure 1, and Plate XI) fully confirms the early descriptions, reveals the full osteology of the skull, and further demonstrates the distinctness of the genus and species among the horned dinosaurs of the Belly River Cretaceous. Mr. Brown in the paper here referred to has proposed the specific name *flexus* for a skull of *Centrosaurus apertus* from the same beds on Red Deer from which the original neck-frill (type) and the supplementary specimens come. The skull described by Mr. Brown was found by the American Museum party in 1912 one mile below the mouth of Berry creek and presumably not far distant from where the type specimen of Centrosaurus was discovered.

There seems to have been a tendency in the horned dinosaurs to produce a separate bony growth on each prominence of the upper part of the skull. Thus the epoccipitals occur in a series along the free border of the frill, one to each convexity, and the epijugal is so named from its situation at the lower extremity of the jugal. Recently Dr. C. W. Gilmore has found in the type of Brachyceratops (Plate VI, figure 3, and Plate X) an ossicle

[1] Bull. Amer. Mus. Nat. Hist., Vol. XXXIII, art. XXXIV, pp. 549-558, 1904.

[2] Ottawa Naturalist, Vol. XVIII, pp. 81-84, 1904; and Trans. Royal Soc. of Canada, second series, Vol. X, pp. 3-9, 1904.

on the top of the nasal horn-core, and in the skull of Centrosaurus figured in Plate XI (Geological Survey collection of 1914) a separate ossification occurs at the upper termination of the rostral bone. Further, at the greatest elevation of the postfrontal above each orbit in the type specimen of Styracosaurus and also in that of *Brachyceratops dawsoni* there is a shallow concavity of somewhat irregular oval outline which has the appearance of being a sutural surface for the attachment of a separate bony growth which became detached before or during fossilization, as was often the case with the epoccipitals and especially with the epijugal. This separate ossification above the postfrontal was evidently an incipient supraorbital horn-core and furnishes the clue to the origin of this horn-core in the horned dinosaurs generally from a centre of ossification distinct from the postfrontal. The supraorbital horn-core is to be regarded, therefore, not as a simple outgrowth from the postfrontal but as a separate element, in the same category with the epijugal and the epoccipitals and like them to become firmly attached to the underlying element with generally a more or less perfect obliteration of the sutural contact. The large posterior projections of the frill in Styracosaurus (Plate III, figure 2, and Plate VI, figure 2) may be regarded as a striking example of extreme enlargement in separate bony growths with loss of any trace of a basal suture. In the supraorbital horn-core a more or less distinct basal engirdling groove or constriction is sometimes present as an indication of where coössification has taken place. Also foramina or deep pits not infrequently occur at the horn base and may be regarded as marking the position of a closed suture.

The presence of epoccipitals on the margin of the neck-frill is distinctive of certain genera. They were developed in all three groups of horned dinosaurs apparently as accessories during specialization, to be abandoned when found useless as appendages to the armature. The primitive Eoceratops was without them, later they appear in Triceratops. In the wholly Belly River Centrosaurus group the specialized Centrosaurus has these separate ossifications in a well-developed state, Styracosaurus has a profusion of them of unusual length, while in

Brachyceratops there is a simple undulation of the frill border. In the Belly River Chasmosaurus epoccipitals form a prominent feature of the frill armature, but in its supposed descendant Torosaurus they have altogether disappeared.

The supraorbital horn-cores have hitherto been regarded as simple outgrowths, and the nasal one as a separate ossification from a single median centre.

As regards the horn-cores Mr. Hatcher, in his monograph, pages 32 and 33, has given his views of their origin. This author stated that "While these horn cores (nasal)are supported by the nasals, and in old animals become firmly co-ossified with them, they nevertheless have their origin in separate and distinct centres of ossification. Moreover, since in young individuals every nasal horn core is seen to have had its origin in a single median centre of ossification rather than in two distinct lateral centres placed one beside the other, it is evident that this horn core is in reality morphologically quite distinct from the nasals. In this respect the nasal horn cores differ greatly from the supraorbital horn cores, which are simple outgrowths from the postfrontals, and therefore are morphologically a part of their supporting elements" . . . . "Morphologically the nasal horn cores may be considered as dermal or epidermal ossifications similar to the epijugals, epoccipitals, the rostral, and the predentary, and as quite distinct from the frontal horn cores."

As just stated the present writer regards the horn-core over the orbit as an ossification separate from the postfrontal. With increased age in an individual a union of the base of this separate ossification (epipostfrontal) with the postfrontal took place with usually a loss later of all trace of the suture.

The type of Eoceratops throws light on the origin of the nasal horn-core. In this specimen this small horn-core is seen to be made up of the anterior end of the nasals and a separate ossification (epinasal) in front of each nasal, as explained in the description of the skull of Eoceratops and shown in the figure of that specimen, proving the quadruple origin of the nasal horn-core, that is, that there were two separate ossifications one in front of each nasal instead of one medium ossification anterior to these bones as believed by Hatcher.

The suture between the left epinasal bone and the left nasal is well shown in the figure of the skull of *Triceratops elatus* Marsh, forming Plate XLIII of Hatcher's monograph. In *T. elatus* the form and position of the epinasal (Plate X, figure 1), as seen in side view, is very similar to that of Eoceratops (Plate X, figure 2), with this difference that in Eoceratops it is more under the upper anterior end of the nasal which extends over it.

Apparently the epinasals are to be classed with the epipostfrontal (supraorbital horn-core) the epijugal, the epoccipitals (episquamosals and epiparietals) the rostral and the predentary as having a dermal or epidermal origin. But whereas the epiparietals were subject to great enlargement (Styracosaurus) as were also the epipostfrontals, the epinasals always remained small taking a subsidiary part only in the formation of the nasal horn-core. Increase in size in the nasal horn-core was dependent on the nasals which extended over and were prolonged above the epinasals, the latter acting as basal supports and becoming ankylosed to the nasals and to each other.

In Plate X the nasal horn-core is shown in four species of horned dinosaurs (*Triceratops elatus*, *Eoceratops canadensis*, *Brachyceratops montanensis*, and *B. dawsoni*) illustrating as many phases of nasal horn-core development from the incipient horn-core made up almost entirely of the epinasals, through progressive stages of nasal enlargement until the horn-core consists mainly of the prolonged nasals with the complete subservience of the epinasals. In *T. elatus* the nasals are slightly elevated behind the epinasals, in *E. canadensis* they are sufficiently prolonged to cover the epinasals above, in *B. montanensis* (Plate X, figure 3) they are further enlarged by an upward extension, while in *B. dawsoni* (Plate X, figure 4) a full development of the horn-core is reached with their still further increase in size to form a weapon of imposing proportions.

In Plate XI is figured one of two remarkably fine skulls of *Centrosaurus apertus* from the Belly River beds of the type locality. This skull in which the nasal horn-core is abnormally bent downward in its upper half, belongs to the collection of 1914. In the other, discovered in 1913, the natural forward curve of this horn-core is preserved.

The skull of *Chasmosaurus belli* reproduced in Plate VIII also forms part of the collection of 1914 from Red Deer river. This specimen and the 1914 skull of Centrosaurus are remarkable in that they have the lower jaw in place and allow of figures being given for the first time of the complete skull in both species.

EXPLANATION OF PLATE I.

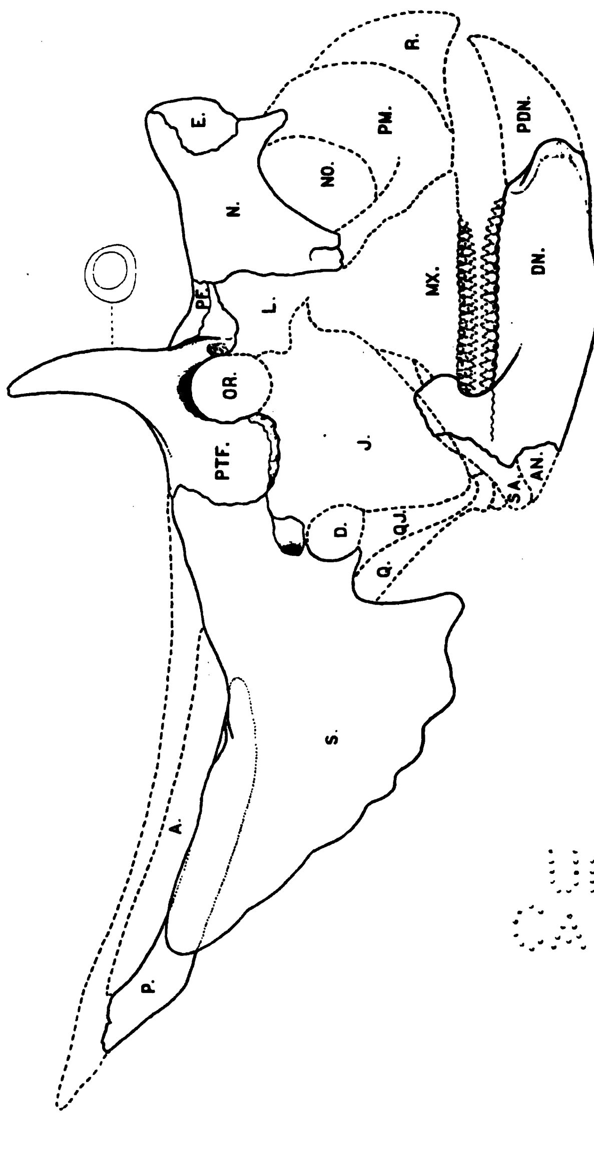
Eoceratops canadensis Lambe; side view of skull. Type; one-ninth natural size. In advance of the supraorbital horn-core are shown outlines of its cross section, the larger above the base, the other near the top.

Abbreviations—*A*, fontanelle of frill; *AN*, angular; *D*, lateral temporal fossa; *DN*, dentary; *E*, epinasal; *J*, jugal; *L*, lachrymal; *MX*, maxilla; *N*, nasal; *NO*, nasal opening; *OR*, orbit; *P*, parietal; *PDN*, predentary; *PF*, prefrontal; *PM*, premaxilla; *PTF*, postfrontal; *Q*, quadrate, *QJ*, quadratojugal; *R*, rostral; *S*, squamosal; *SA*, surangular.

Explanation of Plate I.

Eoceratops canadensis Lambe; side view of skull. Type; one-ninth natural size. In advance of the supraorbital horn-core are shown outlines of its cross section, the larger above the base, the other near the top.

Abbreviations—*A*, fontanelle of frill; *AN*, angular; *D*, lateral temporal fossa; *DN*, dentary; *E*, epinasal; *J*, jugal; *L*, lachrymal; *MX*, maxilla; *N*, nasal; *NO*, nasal opening; *OR*, orbit; *P*, parietal; *PDN*, *predentary*; *PF*, prefrontal; *PM*, premaxilla; *PTF*, postfrontal; *Q*, quadrate; *QJ*, quadratojugal; *R*, rostral; *S*, squamosal; *SA*, surangular.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EXPLANATION OF PLATE II.

Figure 1. Hypothetical form of frill of ancestral ceratopsian; superior aspect.

Figure 2. Frill of *Eoceratops canadensis* Lambe; one-eighteenth natural size; viewed from above.

Figure 3. Frill of *Triceratops flabellatus* Marsh; one-sixteenth natural size; viewed from above. After Marsh.

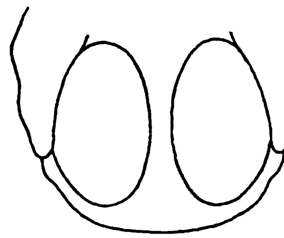
3.

Explanation of Plate II.

Figure 1. Hypothetical form of frill of ancestral ceratopsian; superior aspect.

Figure 2. Frill of *Eoceratops canadensis* Lambe; one-eighteenth natural size; viewed from above.

Figure 3. Frill of *Triceratops flabellatus* Marsh; one-sixteenth natural size; viewed from above. After Marsh.



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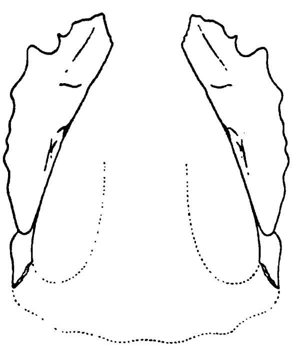

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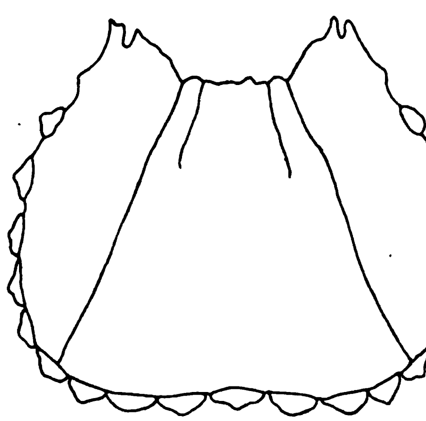

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EXPLANATION OF PLATE III.

Figure 1. Frill of *Centrosaurus apertus* Lambe; one-sixteenth natural size; superior aspect.

Figure 2. Frill of *Styracosaurus albertensis* Lambe; one-twelfth natural size; superior aspect.

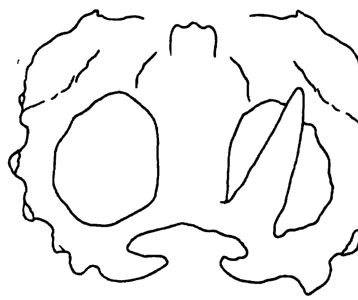
Figure 3. Frill of *Brachyceratops montanensis* Gilmore; one-eighth natural size; superior aspect. After Gilmore.

EXPLANATION OF PLATE III.

Figure 1. Frill of *Centrosaurus apertus* Lambe; one-sixteenth natural size; superior aspect.

Figure 2. Frill of *Styracosaurus albertensis* Lambe; one-twelfth natural size; superior aspect.

Figure 3. Frill of *Brachyceratops montanensis* Gilmore; one-eighth natural size; superior aspect. After Gilmore.



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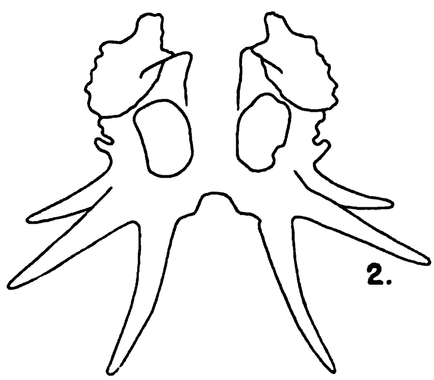

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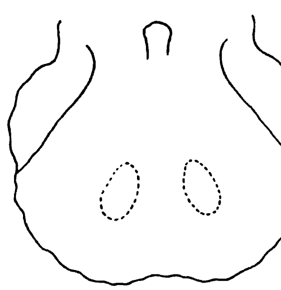

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EXPLANATION OF PLATE IV.

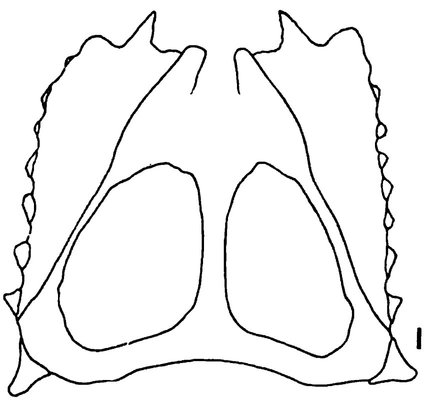
Figure 1. Frill of *Chasmosaurus belli* Lambe; one-twentieth natural size; viewed from above.

Figure 2. Frill of *Torosaurus gladius* Marsh; one-thirty-second natural size; superior view. After Marsh.

Explanation of Plate IV.

Figure 1. Frill of *Chasmosaurus belli* Lambe; one-twentieth natural size; viewed from above.

Figure 2. Frill of *Torosaurus gladius* Marsh; one-thirty-second natural size; superior view. After Marsh.



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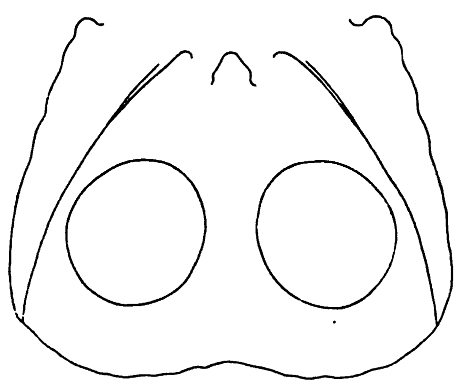

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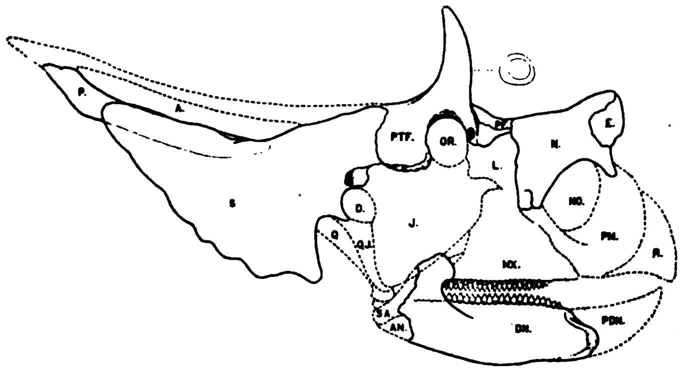
EXPLANATION OF PLATE V.

Figure 1. Skull of *Eoceratops canadensis* Lambe; lateral aspect; about one-fifteenth natural size.

Figure 2. Skull of *Triceratops flabellatus* Marsh; lateral aspect; one-twelfth natural size. After Marsh.



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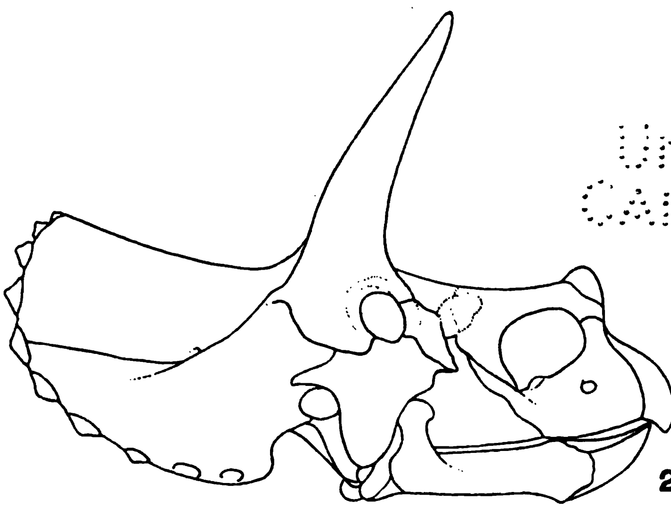

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EXPLANATION OF PLATE VI.

Figure 1. Skull of *Centrosaurus apertus* Lambe; lateral aspect; about one-eighteenth natural size.

Figure 2. Skull of *Styracosaurus albertensis* Lambe, lateral aspect; about one-twentieth natural size.

Figure 3. Skull of *Brachyceratops montanensis* Gilmore; lateral aspect; one-seventh natural size. After Gilmore.

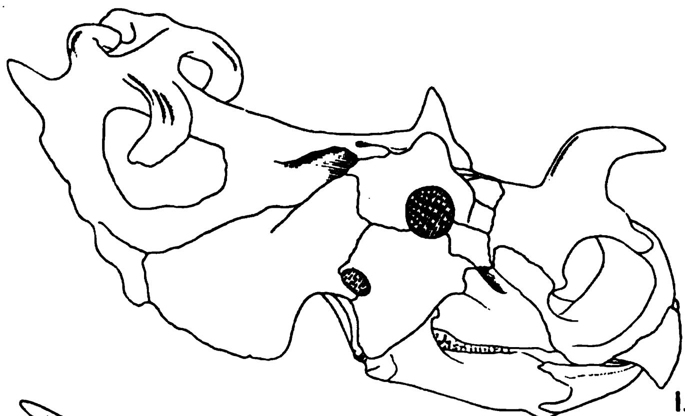
3.

EXPLANATION OF PLATE VI.

Figure 1. Skull of *Centrosaurus apertus* Lambe; lateral aspect; about one-eighteenth natural size.

Figure 2. Skull of *Styracosaurus albertensis* Lambe; lateral aspect; about one-twentieth natural size.

Figure 3. Skull of *Brachyceratops montanensis* Gilmore; lateral aspect; one-seventh natural size. After Gilmore.



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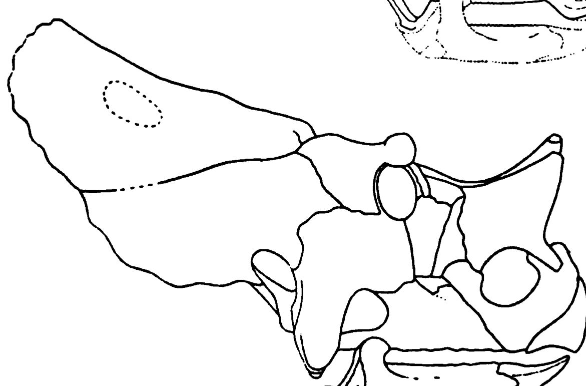

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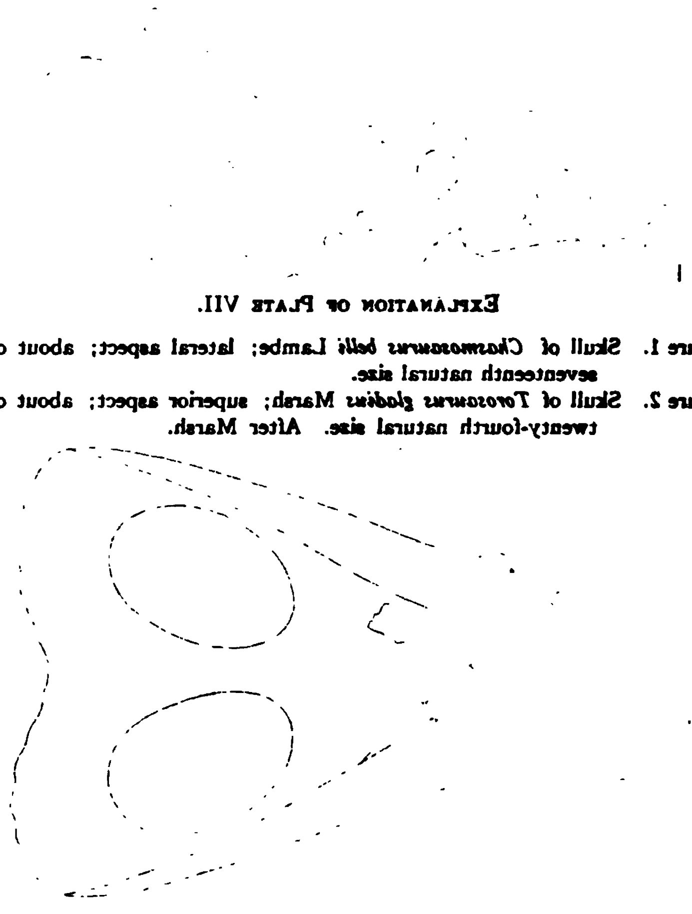
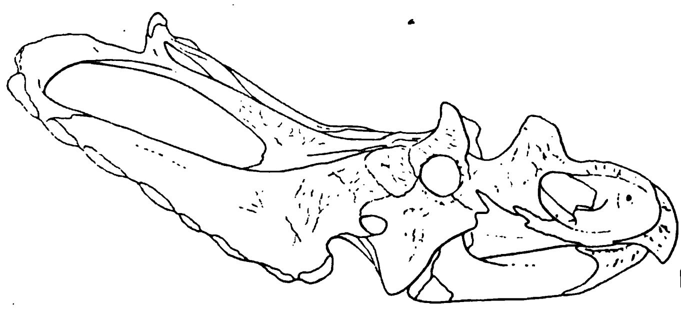


EXPLANATION OF PLATE VII.

Figure 1. Skull of *Chasmosaurus belli* Lambe; lateral aspect; about one-seventeenth natural size.

Figure 2. Skull of *Torosaurus gladius* Marsh; superior aspect; about one-twenty-fourth natural size. After Marsh.



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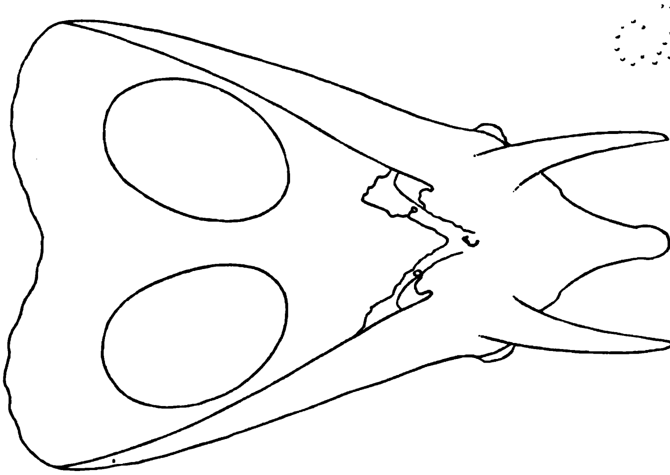

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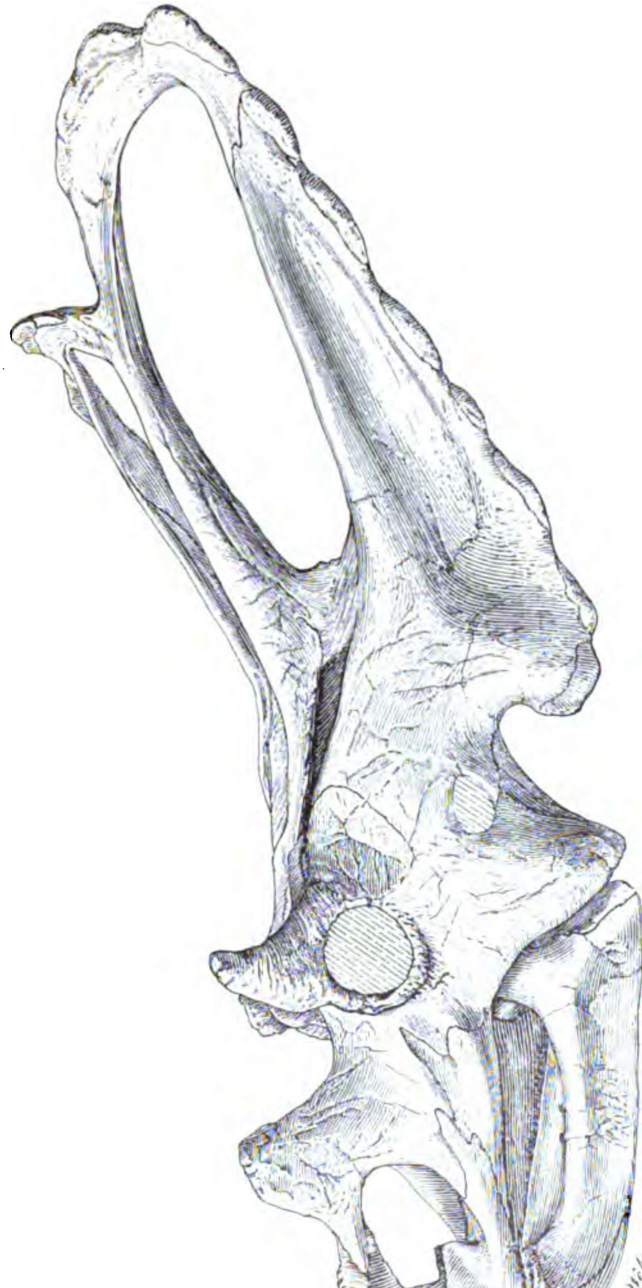
Explanation of Plate VIII.

Skull of *Chasmosaurus belli* Lambe: side view; one-eighth natural size. Belly River formation, Red Deer river, Alberta; collection of 1914 made by the Geological Survey vertebrate palaeontological field party under Charles H. Sternberg.

EXPLANATION OF PLATE VIII.

Skull of *Chasmosaurus belli* Lambe; side view; one-eighth natural size. Belly River formation, Red Deer river, Alberta; collection of 1914 made by the Geological Survey vertebrate palæontological field party under Charles H. Sternberg.



EXPLANATION OF PLATE IX.

Figure 1. *Eoceratops canadensis* Lambe; view of the more anterior portion of the skull from above to show the relation of the elements to each other; one-sixth natural size.

Figure 2. *Centrosaurus apertus* Lambe; view of part of the skull from above for comparison with figure 1; one-sixth natural size.

Abbreviations—*B*, postfrontal fontanelle; *C*, supratemporal fossa; *F*, frontal; *H*, supraorbital horn-core; *L*, lachrymal; *N*, nasal; *NH*, nasal horn-core; *P*, parietal; *PF*, prefrontal; *PTF*, postfrontal; *S*, squamosal.

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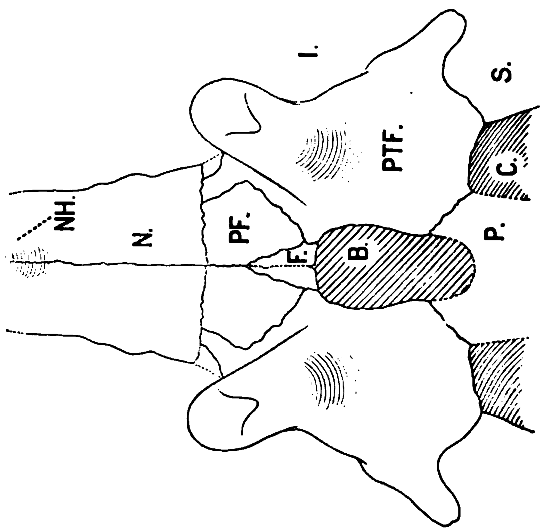

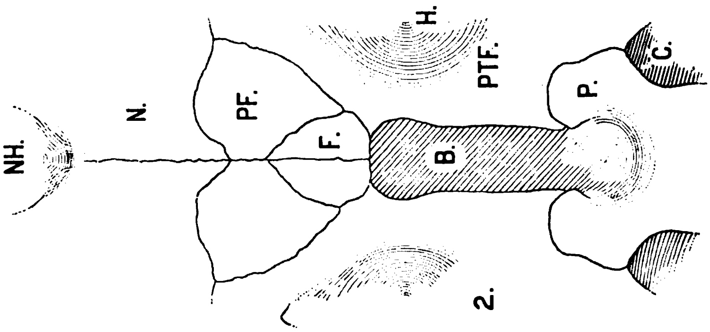

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EXPLANATION OF PLATE X.

Figure 1. *Triceratops elatus* Marsh; side view of nasal horn-core from the right; one-fourth natural size. After Hatcher.

Figure 2. *Eoceratops canadensis* Lambe; nasal horn-core viewed from the right; one-fourth natural size.

Figure 3. *Brachyceratops montanensis* Gilmore; right lateral aspect of nasal horn-core; one-half natural size. After Gilmore.

Figure 4. *Brachyceratops dawsoni* (Lambe); right lateral aspect of nasal horn-core; one-sixth natural size.

Explanation of Plate X.

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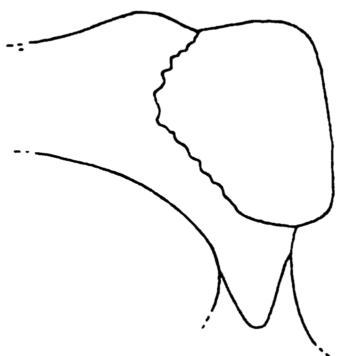
Figure 3. *Brachyceratops montanensis* Gilmore; right lateral aspect of nasal horn-core; one-half natural size. After Gilmore.

Figure 4. *Brachyceratops dawsoni* (Lambe); right lateral aspect of nasal horn-core; one-sixth natural size.



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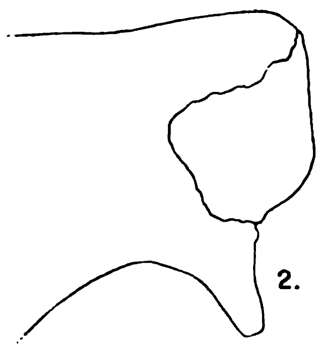

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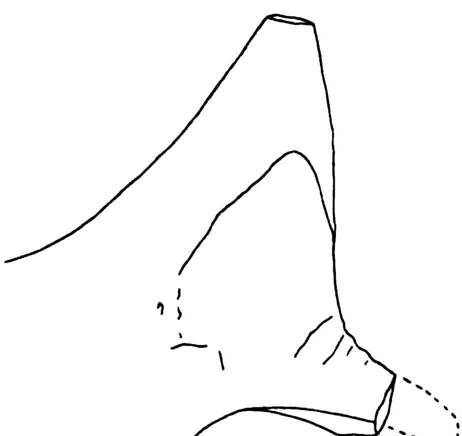

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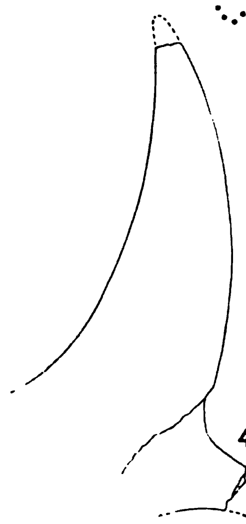

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EXPLANATION OF PLATE XI.

Skull of *Centrosaurus apertus*, Lambe; side view from the right; one-ninth natural size. Belly River formation, Red Deer river, Alberta; collection of 1914 made by the Geological Survey vertebrate palæontological field party under Charles H. Sternberg.

W. D. Ma

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CONTENTS.

Illustrations.

The Cretaceous Carnivorous Dinosaur Gorgosaurus.

INTRODUCTION.

The remains of carnivorous dinosaurs are not nearly as abundantly preserved as are those of the herbivorous dinosaurs. This is found to be so throughout the whole of the dinosaur-bearing beds of the Mesozoic group, proving conclusively that the flesh eating dinosaurs were not present in such numbers as the plant eaters.

Although the field parties of the Geological Survey, in exploring the Cretaceous badland areas in the valley of Red Deer river, Alberta, have been rewarded by finding a number of nearly complete skeletons of herbivorous dinosaurs, only parts of skeletons and separate bones of carnivores had been obtained prior to 1913. In the summer of that year, in the Belly River formation, the discovery was made of the unusually perfect skeleton which forms the subject of the present memoir. This unique specimen from the Belly River formation of Alberta is more complete, so far as the writer is aware, than any carnivorous dinosaur skeleton yet discovered in Mesozoic rocks in any country. This is not surprising when the excellent state of preservation and the abundance of the remains of dinosaurs occurring in the Edmonton and Belly River formations in the valley of Red Deer river are considered.

This specimen constitutes the type of *Gorgosaurus libratus* first described by the writer in April 1914, in the Ottawa Naturalist.[1] In January of the same year the writer published a paper, also in the Ottawa Naturalist, on the fore limb of the type.[2]

The specimen was collected in the summer of 1913, by the Geological Survey vertebrate palæontological field party under Charles H. Sternberg, chief preparator and collector, in the Belly River formation (Cretaceous), Red Deer river, Alberta, 3½ miles below the mouth of Berry creek, on the south side of the river, near the prairie level. The discovery of the skeleton in the field was made by C. M. Sternberg, of this party, who after the specimen had been successfully quarried, devoted much time to the removal of matrix and since the arrival of the specimen at Ottawa has skilfully prepared it for study and exhibition.

The majority of the drawings reproduced in this report have been made by Rudolph Weber and Arthur Miles under the writer's direction.

[1] On a new genus and species of carnivorous dinosaur from the Belly River formation of Alberta,,etc. The Ottawa Naturalist, vol. XXVIII, April 1914.

[2] On the fore limb of a carnivorous dinosaur from the Belly River formation of Alberta, etc. The Ottawa Naturalist, vol. XXVII, Jan. 1914. With one plate.

Figures 32 and 37 are included in the illustrations through the courtesy of Dr. Charles W. Gilmore of the United States National Museum, Washington, D C. Figures 1 to 4 are from photographs taken by C. M. Sternberg in the field.

ORIGINAL DESCRIPTION OF GORGOSAURUS.

The type specimen of *Gorgosaurus libratus* was described in April, 1914, in the following words:

"The osteological characters of one of the carnivorous dinosaurs of the Cretaceous are revealed in a wonderful manner by a nearly complete skeleton obtained last summer. . . . . . . The specimen includes the head, the greater part of the vertebral column, the pectoral and pelvic arches, one at least of the fore limbs complete, both hind limbs also complete, the ribs, and apparently the entire series of abdominal ribs. The cervical vertebræ appear to be missing, but as all of the sandstone matrix has not yet been removed, they, or some of them, as well as the other fore limb, may yet be uncovered. The extreme end of the tail, back of the twenty-second caudal vertebra, was not found.

"The mandible is present and all of the teeth, both upper and lower, are in place, giving the complete dentition. The writer has already published a short description of the fore limb which has not hitherto been known in any of the Cretaceous carnivorous dinosaurs. Nor has a complete series of ventral ribs in any of these reptiles previously been discovered.

"For the undescribed genus of Theropodous dinosaur, brought to light by this magnificent specimen, the name *Gorgosaurus* is proposed. The species may be called *libratus* in reference to the animal's probable well-balanced and easy gait.

"*Gorgosaurus libratus, gen. et sp. nov.*"

"Carnivorous dinosaur of large size, reaching a length of about 29 feet; head narrow and moderately elongate; trunk compact; fore-limbs minute; hind limbs long and robust; tail nearly half the total length of the animal, tapering, and with only a slight lateral compression. In the skull there is a large antorbital vacuity, preceded by a very small opening in the centre of a depressed area. No triangular alveolar plates on the inner sides of the jaws. A foramen present in the sur-angular, far back and near its upper border. No presplenial. Teeth trenchant, powerful, 4 premaxillary, 13 maxillary, and 14 dentary. First tooth of the maxilla similar in shape and size to those of the pre-maxilla. Vertebræ slightly amphicœlus, concave on the sides and be-neath; 2 cervico-dorsals, 11 dorsals, 5 sacrals, and about 34 caudals. Neural spines short throughout the vertebral column. Chevron bones

Figure 1. The discovery of the type of Gorgosaurus in the badlands of Red Deer river, Alberta. Limb bones protruding from the rock, and parts of a foot that had fallen from the slope first drew attention to the specimen.

Figure 2. The 30-foot skeleton of Gorgosaurus was taken up in five sections, the largest of which weighed over a ton. The sections, consisting of the bones held in place by the sandstone matrix, were swathed in burlap dipped in plaster of paris, preparatory to being packed in strong boxes and taken by wagon over the prairie to the nearest railway station. In the above view a section is being lifted by block and tackle into the wagon for removal to the prairie level

Figure 3. The excavation in the clayey sandstone as it appeared after the removal of the Gorgosaurus skeleton.

Figure 4. Sandstone beds of the Belly River formation as exposed in the valley of Red Deer river, Alberta. This view was taken from near the Gorgosaurus "quarry" looking up the river toward Berry creek.

short, beginning with the first caudal. Transverse processes of the caudal vertebræ decreasing in size to and ending with the 14th vertebra. Anterior zygapophyses of the posterior caudals greatly lengthened. Scapula longer than the fore limb. Humerus twice the length of the ulna. Two digits, Nos. II and III, to the manus, of which the phalangeal formula is 2 II, 3 III, the terminal phalanges being claw-bones. Metacarpal IV represented by a proximal vestigial bone. Ilium elongate, plate-like, with a flat upper outline and rounded ends. Preacetabular part shorter than the hinder portion, of which both are strengthened on the outer surface by a prominent, overhanging flange running horizontally at midheight. Ischium terminating narrowly below. Pubis ending in a horizontally expanded foot, of which the posterior extension is the greater. Femur about the same length as the tibia. Metatarsals II, III, and IV elongate, of which III, the longest, is nearly two-thirds the length of the femur. Metatarsal I represented distally by a short vestigial bone, and metatarsal V represented in a similar manner proximally. Four clawed digits to the pes, viz. Nos. I, II, III, and IV, of which the phalangeal formula is 2 I, 3 II, 4 III, and 5 IV. Ventral ribs composite, sixteen in number, overlapping at the longitudinal mid-line of the body, and bearing distally slender, closely applied supplementaries.

"*Gorgosaurus libratus*, apart from its dentition, is remarkable for the extreme shortness of the fore-legs and the great length of the hind ones. The long, narrow ilium rises slightly above the short sacral spines, and, in addition to the horizontal flanges, already mentioned, there are two small strengthening buttresses running upward from the centre of the acetabular border. The length of the metatarsals is surprising. The close application of the vestigial distal end of metatarsal I to metatarsal II is indicated by a slightly concave surface on the latter bone, which gives digit I a forwardly rather than a backwardly directed position in the foot. The vestigial proximal end of metatarsal V is in place in each leg, recalling to mind a similarly reduced bone in *Ornithomimus altus* Lambe, also from the Belly River formation of Alberta.

"Each abdominal rib consists of two well ossified, flattened lengths, which overlap at their inner ends. Outwardly, each lateral half is slightly grooved on its front margin for the reception of a slender rod-like bone (supplementary), which lies closely against the rib and projects but slightly beyond its outer end.

"The four premaxillary teeth are remarkably long and slender, with a keel on each side of a slightly convex inner or lingual surface. They are latterly compressed to a slight extent, evenly rounded in front, with their fore and aft diameter a little greater than their breadth. The first or anterior tooth of the maxilla is similar to the premaxillary teeth, in which respect Gorgosaurus differs from other known genera of Cret-

aceous carnivorous dinosaurs. The other maxillary teeth are long and powerful of the Megalosauroid type, with two serrated keels, one along the front edge, the other behind. In the second maxillary tooth the anterior keel in descending passes slightly toward the inner side of the crown, and this is seen in a lessening degree in the next two or three succeeding teeth. A similar slight variation is seen also in the more anterior teeth of the dentary.

"The chevron bones are intervertebral, but with a greater surface of attachment to the front vertebra of the two. The more anterior ones are bent slightly backward from their midlength. This angulation in succeeding ones becomes more pronounced until the lower edge of the distal half is parallel to the longitudinal axis of the tail. By a gradually increased development and prolongation forward of the anterior angulation at the mid-length of the bone, a 'meat-chopper' shape is attained and adhered to with a gradual diminution in size, more apparent in the depth of the bone than in the length of its 'foot.'

"The long and slender anterior teeth (premaxillary and first maxillary) of Gorgosaurus are very different in shape from the robust supposed anterior teeth of *Deinodon horridus* of Leidy. In all the large Cretaceous carnivorous dinosaurs, the majority of the teeth, apart from the more anterior ones, are remarkably similar in the different genera and do not afford data for generic distinctions.

"Another large form of carnivorous dinosaur, having supporting alveolar plates on the inner sides of the jaws, occurs in the Belly River formation of Alberta and is represented in the collection of 1913."

ORIGINAL DESCRIPTION OF THE FORE LIMB.

The description of the fore limb, which appeared prior to the above, was as follows:

"The first impression received of the fore limb is its extremely small size.

"The arm has been pressed upward so that the humerus lies beside the back border of the blade of the scapula with its front face directed forward and its inner surface outward, its head remaining within the glenoid cavity.

"The fore-arm is flexed downward and the manus is closed with the claw-bones uppermost. The ulna and radius lie together, and the digits, of which there are two, are in place. From the regular succession of the phalanges of the digits to each other it is presumed that none of them is missing. The digits are regarded as Nos. II and III, and there is a vestigial metacarpal IV, consisting of a short, slender bone, slightly curved and tapering to its distal end.

"Metacarpal II is very short, being only about one-half the length of metacarpal III. There are only two phalanges to digit II, an elongated one and a comparatively large, laterally compressed, curved, and sharply pointed ungual. In digit III the first phalanx is short, the second long, and the distal one claw-shaped but smaller than that of digit II. In the ungual phalanx of digit II there is a decided claw-groove. The first phalanx of digit II and the first and second of digit III have a deep pit on each side of the distal end. In the corresponding part of the metacarpals there is only a slight irregular depression.

"Four carpal bones are preserved between the ulna and radius and the metacarpals, but they are slightly displaced. One is roughly discoidal and larger than the others which are compressed ovoid in shape. The largest one occurs at the proximal end of metacarpal III, the other three lie together at the distal end of the radius. The ulna and radius are solid except for a small axial area of cancellous bone.

"As already mentioned, the elements of the manus follow each other in regular succession and are apparently all in place with none of the phalanges missing. The phalangeal formula revealed is, therefore, probably the correct one.

"The figure accompanying this description shows the relative size of the fore limb and the scapula with the coracoid. The limb is here shown in lateral aspect, in a natural position below its articulation with the scapula, and with the digits only slightly curved.

"Attention is drawn to the extreme shortness of metacarpal II and the elongation of the penultimate phalanx in each digit. A similar lengthening of the corresponding phalanges is seen in the manus of the small Jurassic *Ornitholestes hermanni* Osborn, in which also there are two digits, a vestigial metacarpal IV, and an enlarged ungual phalanx in digit II."

There are reasons for believing that two forms at least of large carnivorous dinosaurs occur at the Belly River horizon of the Cretaceous of Alberta, leaving out of consideration the extremely slender Ornithomimus. Of these larger flesh-eaters Gorgosaurus is the only one of which comprehensive information has been obtained.

GENUS DEINODON.

Reference may here be made to the genus Deinodon of Leidy[1], 1856. This genus was primarily based on teeth of carnivorous dinosaurs from the Judith River Cretaceous on Missouri river, Montana (then included in Nebraska), U.S.A., a horizon synchronous, or nearly so, with the Belly River formation of Alberta. The teeth on which Dr. Leidy based his

[1] Proc. Acad. Nat. Sc. Phila., vol. VIII, p. 72.

genus were figured and more fully described by him in a paper published in 1860[1]. From these figures and descriptions it is most probable, in the light of our present knowledge of the dentition of Cretaceous carnivorous dinosaurs, that at least two carnivorous forms, one large and the other small, are included under this generic term. In all probability the small tooth with a U-shaped transverse section, Figures 41-45, does not belong with the large sized teeth, Figures 21-40. Referring to all of these teeth Dr. Leidy wrote (p. 73 of his 1856 paper) "having been discovered together, and possessing the same structural appearances, I suspect them to have belonged to one and the same species." In this opinion Dr. Leidy was probably correct, if we exclude the smallest tooth mentioned by him (Figures 41-45). which to all appearances did not belong to Deinodon.

Later, in 1868[2], Leidy separated the U-shaped, posteriorly truncate teeth from the others, proposing the genus Aublysodon for their reception. That this course was erroneous is probable from the evidence of the discoveries of recent years. We know that the Jurassic Allosaurus, and Gorgosaurus and Tyrannosaurus of the Cretaceous have the upper anterior teeth truncate posteriorly. In the case of Gorgosaurus the first maxillary tooth in addition to those of the premaxillary is of this shape, the remainder of the maxillary teeth and those of the dentary having the well known trenchant, laterally compressed form with a lenticular cross section near the tip.

If the majority of the teeth described by Leidy belonged to a single individual, and the name Deinodon is retained, a form clearly distinct from Gorgosaurus is represented differing from the latter in having larger and more robust upper anterior teeth in comparison with which those of Gorgosaurus are remarkable for their slenderness.

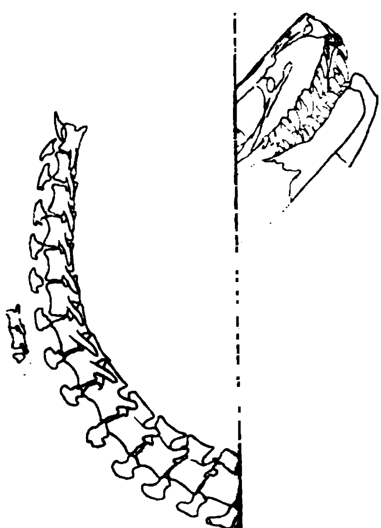
If on the other hand these teeth belonged to two separate individuals, the trenchant teeth to one and the truncate to another, then in neither case are sufficient diagnostic characters available for generic or specific differentiation.

POSITION OF THE SKELETON OF GORGOSAURUS AS FOUND.

The skeleton of Gorgosaurus was discovered in a thick bed of tough clayey sandstone. The phalanges of the left hind foot were first noticed lying as they had fallen, after having weathered from the rock, at the base of a low bluff. What proved to be abdominal ribs, and the metatarsals of the left foot were observed protruding slightly from the steep

[1] Trans. Am. Phil. Soc., "Extinct vertebrata from the Judith River and Great Lignite formations of Nebraska," p. 143, pl. 9, figs. 21-48.

[2] Proc. Acad. Nat. Sc. Phila., vol. XX, p. 198.



Fig

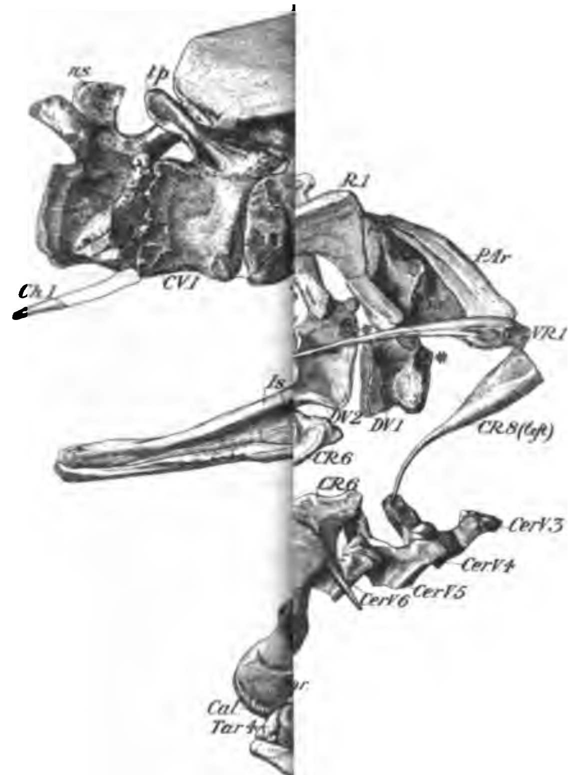


Figure 7. Rig nb, the right

rocky slope at a level above the loose phalanges as shown in the reproduction of the photograph, Figure 1, taken at the time of the discovery. The removal of a thickness of from 3 to 12 feet of sandstone revealed the skeleton lying on its right side.

The left hind limb was intact and drawn up in a natural position. The skull was found apart from the neck vertebræ, and had been crushed and otherwise damaged in its upper hinder part. The left shoulder blade and the whole of the left fore limb, with the exception of two phalanges and some fragments of the fore arm, were missing, as well as the greater part of the left half of the series of abdominal ribs. The neck had been displaced and had suffered considerable injury, but behind it the whole of the vertebral column was in place with the exception of a few vertebræ at the end of the tail.

Later it was found that on the right, or under side of the specimen as found, both limbs were present, as well as the scapula, coracoid, thoracic ribs, and abdominal ribs. The fore limb, bent at the elbow and wrist had been thrust upward, and the hind limb, drawn tightly up on itself, lay in line with the vertebral column (Figures 5, 6, and 7).

Explanatory Lettering of Figures 6 and 7.

As, astragalus.	*M*, manus.
Cal, calcaneum.	*Mt*, Metatarsal.
CerV, cervical vertebra.	*ns*, neural spine.
Ch, chevron.	*P*, pubis.
Cor, coracoid.	*PAr*, prearticular.
CR, cervical rib.	*R*, thoracic rib.
CV, caudal vertebra.	*Ra*, radius.
Dt, digit.	*Sa*, surangular.
DV, dorsal vertebra.	*Sc*, scapula.
F, femur.	*SV*, sacral vertebra.
Fb, fibula.	*T*, tibia.
H, humerus.	*Tar*, tarsal bone.
Il, ilium.	*tp*, transverse process.
Is, ischium.	*U*, ulna.
LR, lateral rib bone.	*VR*, abdominal rib.
LV, lumbar vertebra.	*, articular surface.

Since the original summary of the principal characters of Gorgosaurus was published further study of the type makes it desirable to state that the supposed absence of alveolar plates on the inner side of the jaws in the type may be due to non-preservation, and the same may be said of the presplenial. It will be noticed also in the following pages that the vertebral formula has been slightly modified, that the two digits of the manus are now regarded as being Nos. I and II, that there are thought to be nineteen instead of sixteen composite ventral ribs, and that another bone of the carpus has been brought to light. Also a slight change has been made in describing the angulation of digit I of the pes.

DESCRIPTION OF THE TYPE OF GORGOSAURUS.

SKULL.

The pressure to which the type of Gorgosaurus has been subjected has injured the back half of the head more than any other part of the skeleton. The head as a whole has been compressed but in the neigh-

bourhood of and behind the orbits the cranium has been also crushed downward and fractured and many of the bone fragments lost. The anterior half of the skull is better preserved, more particularly on the

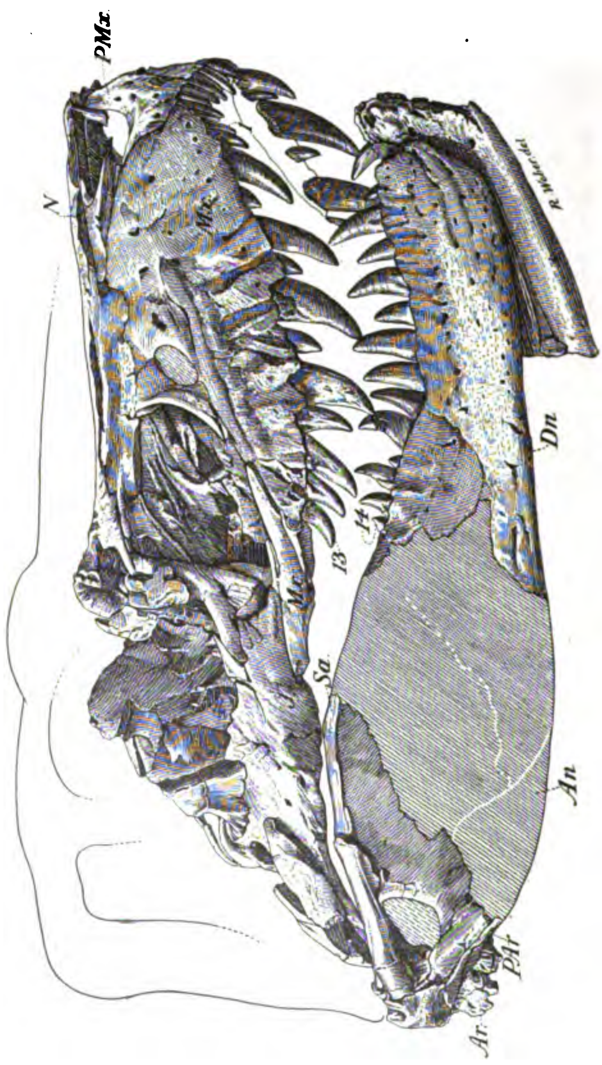


Figure 8. Skull of the type of *Gorgosaurus libratus*; right lateral aspect; ⅓ natural size. Cat. No. 2120. *An*, angular; *Ar*, articular; *Dn*, dentary; *J*, jugal; *Mx*, maxilla; *N*, nasal; *PAr*, prearticular; *PMx*, premaxilla; *Sa*, surangular; 1 and 13, first and thirteenth maxillary teeth; 14, fourteenth mandibular tooth.

right side where the outer surface of the maxilla, premaxilla, and dentary are seen to advantage. The anterior end of the nasal bones and the left premaxilla are in equally good condition. All the teeth of the right maxilla, of both premaxillæ and of the right dentary as well as the more anterior ones of the left maxilla and dentary are in place, and in each

case display the shape of the crown to the tip with all details of structure and change of form (Figure 8).

Maxilla. The maxilla is large, obtusely pointed in front in lateral aspect, and highest behind where it is deeply emarginated by a large preorbital vacuity. The alveolar border is irregularly undulating. The outer surface is rugose, and displays many foramina in the front part generally and above the hinder alveolar border.

The preorbital vacuity is subtriangular in shape, highest behind with a rather straight posterior margin and a rounded anterior one which latter is directly above the ninth maxillary tooth; its length exceeds its height. In advance of and close to this large opening is a small, oval one, the anterior preorbital vacuity, fully within the maxilla.

	Mm.
Height of preorbital vacuity at its midlength	147
Length of the same at its midlength	180
Long diameter of anterior preorbital vacuity	60
Short diameter of the same	28

The maxilla does not enter into the formation of the narial opening but is excluded therefrom by a downward process from the nasal and a posterior extension upward of the premaxilla which meet and bound the opening posteriorly.

Mandible. When the skull was found there was a gap in the right ramus of the mandible behind the dentary. Nearly two-thirds of the surangular in front had broken away and been lost, with some fragments of the posterior border of the dentary. The angular was missing except possibly a small portion of it posteriorly, and the prearticular was not found. The dentary and the hinder part of the surangular had remained in their proper position relative to each other, giving 950 mm. as the exact length of the mandible. The outer surface of the dentary was in an excellent state of preservation.

Of the left ramus the surangular and prearticular, complete though crushed, were found displaced (Figure 7, *Sa* and *PAr*), and the dentary was represented by its anterior half which had shifted forward and downward as figured. The prearticular is a long, narrow, thin, hook-shaped bone which curves anteriorly upward to the inner, superior border of the surangular.

Surangular. A particularly well preserved and nearly perfect right surangular, found separately, but apparently referable to Gorgosaurus, is shown in Figure 9. It is free from any distortion and all details of surface markings are sharply defined. In size it is slightly larger than the surangular of the type. On account of its excellent state of preservation it is described and figured here in preference to that of the type.

The separate right surangular, Figure 9, has the form of a somewhat lenticular plate about three times as long as high, narrowing to

either end, and highest at midlength. It is thickest near the posterior end, continues modera ely strong along the superior border and thins downward to an irregularly undulating lower edge.

There is a large posterior opening, nearly circular in outline, at a distance of one-fifth of the bone's length from the posterior end, and placed

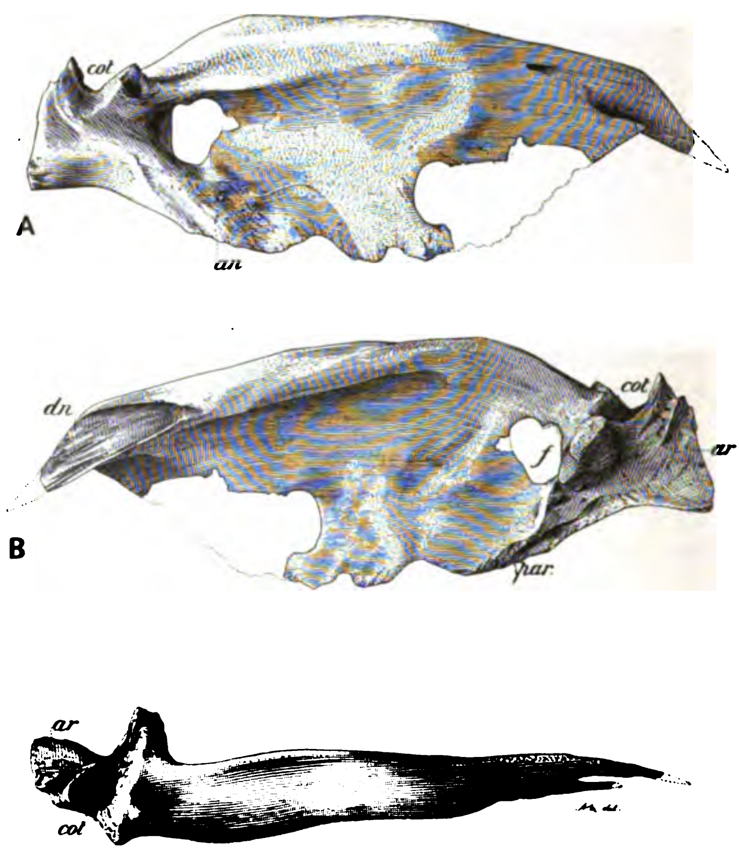


Figure 9. Separate surangular of Gorgosaurus; ½ natural size. Cat. No. 2193. A, exterior view; B, interior view; C, superior view. *an*, surface for angular; *ar*, surface for articular; *cot*, mandibular cotylus; *dn*, surface for dentary; *f*, posterior opening; *par*, surface for prearticular.

at about midheight. It is relatively larger th n the mandibular opening in Dryptosaurus (Albertosaurus), being about one-half as high again.

The upper part of the bone is bent strongly inward from near the posterior end for the greater part of its length forward, the amount of

inturn diminishing toward the front. Behind the posterior opening the bone is greatly thickened and a short, stout, inwardly directed process is developed whose anterior surface is in continuation with the posterior margin of the opening. At the anterior margin of the opening the bone is thin and continues so with little variation to the front.

Exteriorly the posterior thickening of the bone is excavated in front for the opening which occupies nearly the whole of the excavation. Superiorly it extends forward horizontally above the opening and for a short distance beyond it as a strong narrow ridge, adding to the breadth of the superior surface and greatly strengthening the bone at this part. Beneath the opening the thickening diminishes rapidly forward. The opening is thus seen to be sunken in the general level of the outer posterior surface. The remainder of the exterior surface has minor undulations in a general flattened convexity. The superior surface is broad posteriorly and flat with a slightly outward and downward slope. Passing forward it becomes rounded with a diminishing breadth. Viewed from within the surangular presents a general concave surface in advance of the inwardly directed process, deeply excavated beneath the superior border and slightly concave elsewhere.

In the lower front portion of this separate surangular a considerable part of the border is missing in advance of a smooth incurved edge, rather more than a semi-circle in extent, which may represent the even curve of a deep emargination, or possibly a nearly circular opening through the thin bone with the front margin broken away. In the left surangular of the type such an opening is not present nor does a deep emargination occur antero-inferiorly. Although the undulatory nature of the lower front border of the surangular in Gorgosaurus might allow of an unusually deep incurve of the edge as an individual variation yet the regularity of the curve and its extent in this particular specimen is suggestive of an opening within the bone. A large, oval, anterior opening is described and figured by Marsh as occurring in the surangular of *Ceratosaurus nasicornis* of the Jurassic.

The surangular's contribution to the transversely placed mandibular cotylus is behind the broad flat posterior portion of the superior border and separated from it exteriorly by a pointed elevation curving upward, forward, and slightly inward. This part of the cotylus is well excavated and is above and exterior to the greater portion of the large, roughened, nearly vertical surface for the articulation of the articular. It extends on to the inwardly directed process which at this point gives the surangular its maximum breadth. The suture between the surangular and the articular strikes obliquely back across the cotylus from within outward, the floor of the cotylus rising to the suture and indicating its bifossate nature as described and figured by the writer in his

report on Dryptosaurus (Albertosaurus) from the higher horizon of the Edmonton[1].

Internally the surface for the articulation of the prearticular is seen for a considerable distance along the lower border in advance of the surface for the articular. It is rugose and narrow as figured.

On the inner side of the prolonged, front termination of the superior border is a depressed surface, much longer than high, and horizontally striated in the direction of its length (*dn*, Figure 9B), for the articulation of the dentary. A short, forwardly directed, laterally compressed process developed on the outer side below the narrow upper termination of the bone overlaps a small portion of the posterior border of the dentary providing an interlocking of the two elements and further strengthening a sutural union which was already a strong one.

Externally a very clearly defined rugose area passing forward and downward from beneath the posterior opening marks the extent of the overlap of the angular behind (*an*, Figure 9A). Anteriorly this element by a sharp inward and then upward bend enters into the formation of the lower border and inner surface of the mandible.

A foramen leads forward through the bone to the outer surface from the anterior end of the inner concavity under the overhanging superior border. Other foramina of smaller size lead into the interior of the bone. These occur in the cotylus, in the surface for the articulation of the articular, and near the hinder margin of the posterior opening in the curve of the excavation encircling it behind.

Measurements of Separate Surangular, Cat. No. 2193.

	Mm.
Maximum length (525 mm. + estimated length of fragment missing from anterior end)	560
Maximum height	196
Thickness 18 and 45 mm. in advance of the anterior margin of the posterior opening	4
Vertical thickness of inturned superior border near its inner edge slightly behind the midlength of the bone	21
Horizontal thickness of superior border at posterior end of articular surface for dentary	27
Vertical thickness between superior surface and upper back margin of posterior opening	36
Vertical diameter of posterior opening	55

Teeth. In Gorgosaurus there are four teeth in the premaxilla, thirteen in the maxilla, and fourteen in the dentary, a number exceeding by one (or two) that of Tyrannosaurus, of a higher horizon in the Cretaceous, which has four premaxillary, twelve maxillary, and from thirteen to fourteen dentary teeth.

One of the principal distinctive characters of the dentition of Gorgosaurus is the similarity of the first maxillary tooth in size and shape to those of the premaxilla.

[1] Geol. Surv., Can., Cont. Can. Pal., vol. III, pt. III.

The side teeth in both jaws are large, laterally compressed with an anterior and a posterior serrated keel; they taper to a rather obtuse point and curve slightly backward, the curvature being most accentuated in the distal half of the crown (Figures 10 and 11). Those of the upper jaw reach a greater size than those below. In these teeth both the anterior and posterior faces are flattened in an increasing degree from a short distance from the tip to the base of the crown, the anterior keel

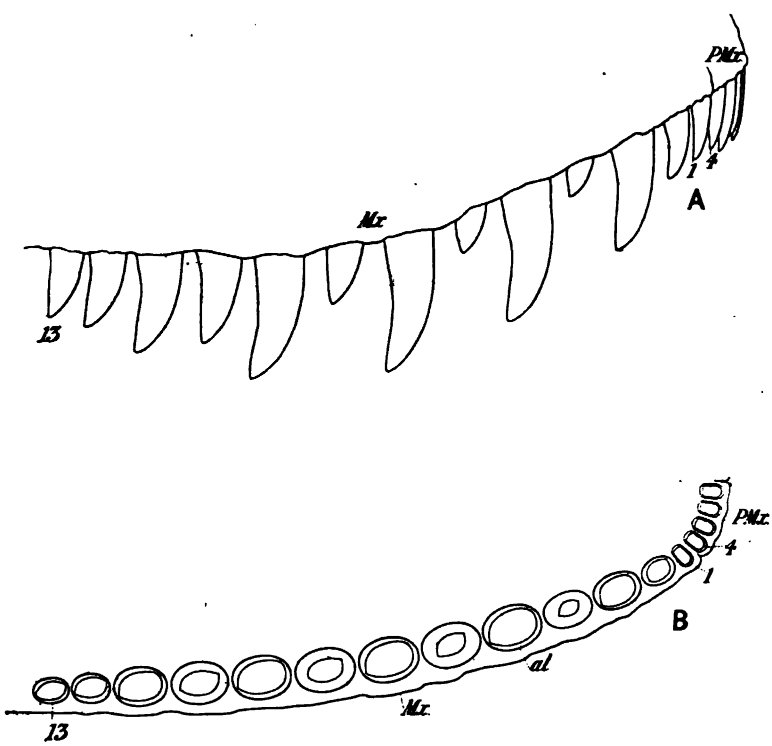


Figure 10. Right premaxillary and maxillary teeth of the type of Gorgosaurus; $\frac{1}{3}$ natural size. A, outer aspect. B, transverse sections. *al*, alveolus; *Mx*, maxilla; *PMx*, premaxilla; 4, fourth premaxillary tooth; 1, first maxillary tooth, 13, thirteenth and last maxillary tooth.

passing gradually inward and defining the inner boundary of the anterior face, the posterior keel marking the outer limit of the posterior face. The anterior keel ends at about one-third of the crown's length from the base, but the posterior one is continued to the base. The anterior flattening of the crown beyond the cessation of the front keel is conspicuously more broadly transverse than in the corresponding part of the tooth posteriorly where the flatness generally retains a slight obliquity

on the inner side of the keel. The outer and inner faces likewise become increasingly flat as the base is approached. For a short distance from the tip the teeth are lenticular in cross section with a keel at each end of the lens. Beyond this the cross section, due to the flattening of the faces, becomes increasingly more subovate until at the base a subquadrangular outline is reached, the anterior transverse diameter being greater than the posterior one.

The keels are serrated throughout their full extent, there being eleven or twelve serrations in a space of 5 mm. in the larger sized teeth and nine or ten in the smaller ones. The serrations are transversely

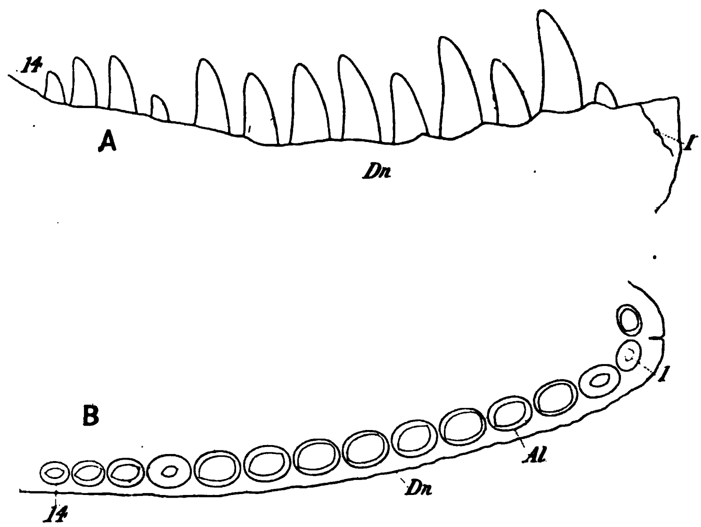


Figure 11. Right mandibular teeth of the type of Gorgosaurus; ½ natural size. A, outer aspect; B, transverse sections; *al*, alveolus; *Dn* dentary; 1, first mandibular tooth; 14, fourteenth and last mandibular tooth.

compressed, and remarkably regular in alignment, with a scarcely perceptible decrease in size near the tip and toward the base of the tooth.

The majority of the maxillary teeth are identical in general form with those of the mandible.

In a number of separate teeth, from the Belly River formation on Red Deer river, indistinguishable from those of Gorgosaurus, the middle of one of the lateral faces is considerably worn for some distance from the tip on which the wear has only been sufficient to efface the minute serrations of the keel. As the upper teeth closed outside those of the mandible any wear, not on the point, would result from the contact of the inner surface of the upper teeth with the outer surface of the lower ones. This lateral wear of the crown is the only means by which an

upper tooth can be distinguished from a lower one—unless one of the side faces of the crown is abraded, a left mandibular tooth is not distinguishable from a right maxillary one, nor a right tooth of the mandible from a left maxillary one.

A peculiar feature of the side teeth of the type specimen of Gorgosaurus is the almost total absence of signs of wear or abrasion. Not one of the side teeth shows any lateral wear, and even at the tip the surface has been so little affected through use that the minute serrations of the keel are not obliterated. The absence of lateral wear would indicate that the maxillary teeth passed clear of the mandibular ones in this particular individual. The small or not fully protruded teeth might be expected to show few signs of wear at the tip but not so in the longer ones which would bear the brunt of feeding. The lack of wear on the points of these teeth in the type specimen suggests that the individual was young and probably also that the food was soft without much abrasive effect. This in the case of a carnivorous dinosaur indicates most probably that the flesh of a carcass, possibly not always freshly killed, was torn from the bones and that the latter were le t untouched.

The premaxillary teeth, four in number (Figure 12), a e remarkable for their slenderness in comparison with the robust side teeth of both jaws. They are laterally compressed with flat sides, the fore and aft diameter exceeding the transverse one, evenly convex transversely in front, and truncate on the posterior or lingual face. Two minutely serrated keels are present, one on either side of the narrow posterior face which is slightly convex between them. The anterior transverse diameter slightly exceeds the posterior one. These teeth are slender throughout. As viewed from the front they are rod-like in form and narrowly rounded below. In lateral aspect they are relatively broader, the back face is almost straight to the tip, to which the front face curves rapidly backward below.

The first maxillary tooth is similar in size and shape to those of the premaxilla.

These narrow upper front teeth were, in their downward direction, probably only very slightly inclined backward. In the type specimen all the teeth of the upper jaw, and some of the lower ones, have been pressed backward to some extent, the normal position of the teeth in both jaws being probably in a nearly vertical direction leaving out of consideration the slight backward curvature found in all the teeth near the pointed end.

The other twelve teeth of the maxilla are all of the trenchant shape already described and form a series of which the second, twelfth, and thirteenth are smaller than the others, the largest and longest, when fully protruded, being the fifth to the ninth inclusive.

None of the fourteen mandibular teeth reaches as large a size as the middle ones of the maxilla; the teeth of the mandible form a more uniform series of smaller size. The third to the tenth would be of about equal size when fully protruded; beyond these at either end there is a diminution in size, the fourteenth being the smallest. The first, owing to its anterior position, has developed a broadly convex front face, the keels occurring one on either side of the flatly convex posterior face, suggesting an approach to, although the tooth remains more robust than the premaxillary teeth.

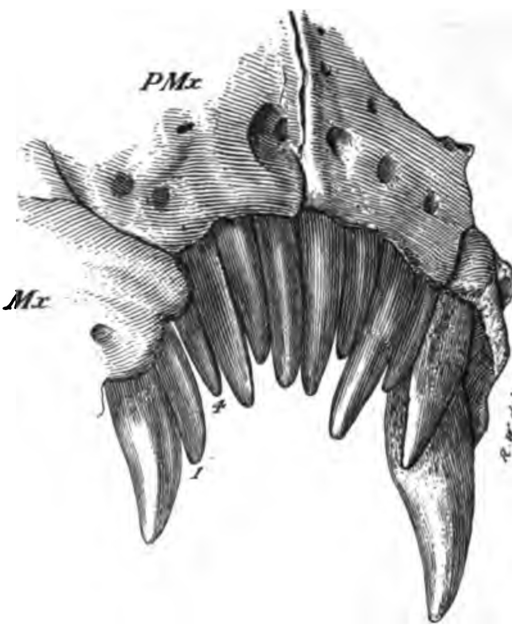


Figure 12. Premaxillary teeth of the type of *Gorgosaurus libratus;* anterior aspect ½ natural size. *Mx,* maxilla; *PMx,* premaxilla; 1, first maxillary tooth; 4, fourth premaxillary tooth.

The teeth replace each other from beneath, apparently as in the living Ghavial (*Gavialis gangeticus*) of India. In Gorgosaurus it is seen that a new tooth makes its appearance on the inner side of the base of the old tooth. The root of the latter is absorbed at this point allowing the new tooth to enter into its central cavity. With increased size the growing tooth, through pressure exerted directly from beneath, ejects the old tooth whose root has been weakened by further absorption. Even before a new tooth has grown sufficiently large to protrude beyond the margin of the alveolus a germ tooth may be formed, to be ready in

its turn to become functional (Figure 13). We thus find in a carnivorous dinosaur provision for a rapid replacement of teeth functioning in a single row, the mode of succession being identical, so far as we can judge, with that of the existing Gavialis. The inner face of the roots of old teeth is usually slightly concave and it is here that the tips of new teeth are first observed pressing against the old ones which they are later to replace. With the partial absorption of the root of an old tooth, the new one by moving to the centre of the alveolus, directly beneath the old tooth, would gain a position more advantageous for pressure against the tooth, and at the same time make room for the formation of the succeeding germ.

The old teeth were lost alternately to some extent, a provision of nature by which large gaps in the series were avoided This is well shown in the type specimen where the side teeth in full use are seen to alternate rather regularly with new ones incompletely protruded.

Attention is drawn to the fact that the lateral teeth of Gorgosaurus are lenticular in cross section only near the tip, and that they are all similarly flattened on the front and back faces near the base, as well as on the sides (buccal and lingual) as already mentioned, the front keel passing inward so as to be hidden in an outer view of the jaw. In this, as in a number of other particulars, the teeth of Gorgosaurus differ from those of Tyrannosaurus[1] in which there is a transition backward in the jaws from those having a sub-oval transverse section to posterior ones of a lenticular section with the serrated keels on the anterior and posterior border of the crown.

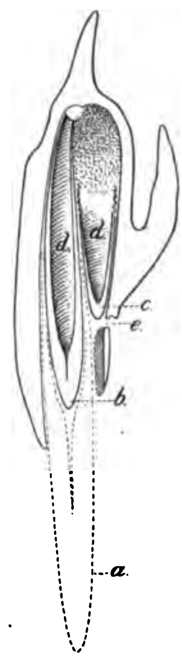


Figure 13. Transverse section of maxilla of Gorgosaurus through alveolus of sixth tooth to show mode of tooth replacement; ½ natural size. Cat. No. 2270. *a*, position of ejected tooth; *b*, new tooth not yet protruded; *c*, germ tooth forming on inner side of alveolus; *d*, pulp-cavity; *e* foramen.

Vertebral Column.

The vertebral formula of Gorgosaurus may be stated to be as follows: C, ?9; C-D, ?2; D, 11; L,1; S,5; C,36∓.

The majority of the vertebræ are either represented or present in the type. Assuming the number of cervicals to be nine, all of them are represented with the exception it is thought of the atlas and axis, possibly of the atlas only. From, and including, the first dorsal the vertebræ are present as a continuous series up to the twenty-second

[1]As described by Osborn. Crania of Tyrannosaurus and Allosaurus: Memoirs of the Am. Mus. Nat. Hist., new series, vol. I, pt. I, 1912.

caudal inclusive, beyond which some displaced caudals belonging to the type specimen were recovered. Two cervico-dorsals may have been present.

Cervical Vertebræ. The neck vertebræ of the type had suffered from surface exposure at the time the skeleton was discovered. They lay with the right side downward, and the centra and the majority of the left zygapophyses had disappeared through weathering. What remained intact beneath the surface of a short rock slope consisted mainly of neural spines, and right zygapophyses in proper relative position to each other. Eight vertebræ are represented in the series (Figure 14A) of which part of the right postzygapophysis is all that remains of the anterior one. Comparison with the cervical series of Tyrannosaurus as described by Osborn (1906),[1] reliance being placed principally on the shape, length, and direction of the neural spines, and the form of the zygapophyses, has suggested the propriety of considering the series as inclusive of the third to the ninth cervical with the posterior one a cervico-dorsal. If the right postzygapophysial fragment in reality belongs to the axis instead of to the third cervical then the succeeding vertebræ would be numbered accordingly and the last of the series of eight would become the ninth and last cervical.

Presumably then seven cervical vertebræ are represented in the specimen out of a total of nine, the parts preserved being principally zygapophyses with their processes and neural spines of, it is thought, the third to the ninth vertebra both included, Figure 14A. With these, forming the posterior end of the series, are parts of what is considered to have been the anterior one of two cervico-dorsal vertebræ.

The cervical vertebræ, as determined, are represented by the following parts:

Third cervical;—fragment of the right postzygapophysis only.

Fourth, fifth, sixth, and seventh cervicals;—the right pre- and postzygapophyses, the neural spine, and the base of the right transverse process.

Eighth cervical;—the right prezygapophysis, the right and left postzygapophyses, and the right transverse process (with cervical rib, Figure 21B). Neural spine not preserved.

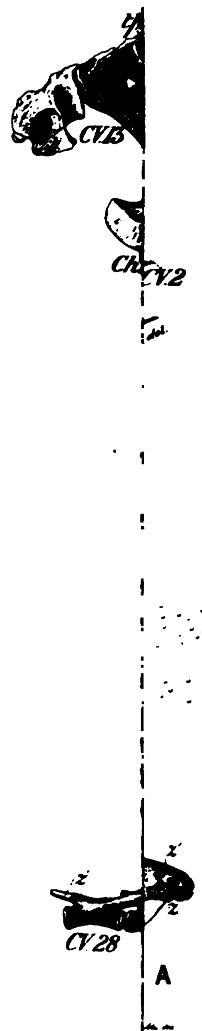
Ninth cervical;—the right and left prezygapophyses, the right and left postzygapophyses, the lower portion of the neural spine, and the right transverse process.

First cervico-dorsal;—the right prezygapophysis and the base of the right transverse process. No neural spine preserved.

The above give a combined length of about 648 mm. (25½ inches) for the seven cervical vertebræ represented.

In these vertebræ the neural spines are short, rather irregular in lateral outline above, laterally compressed, excavated below on their narrow front and back faces, and placed rather far back over the posterior

[1] Tyrannosaurus, Upper Cretaceous carnivorous dinosaur (second communication); Bull. Am. Mus. Nat. Hist., vol. XXII, art. XVI, p. 287, fig. 3.



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half of the centrum. Toward the base they increase rapidly in a fore and aft direction. In the type the spine is preserved to its full length in the fourth, fifth, and seventh vertebræ; that of the sixth is shorter, unduly so possibly on account of incomplete preservation distally; in the eighth and ninth the spine bases only are left. The zygapophyses, borne on strong, heavy processes are large, almost circular in outline, and are best seen in the specimen in the fourth, fifth, and sixth vertebræ where they and their processes have apparently been least affected by distortion (Figure 14A). A diapophysis is directed downward and backward from beneath the prezygapophysial process for articulation with the rib tubercle. The diapophysis in its entirety is preserved only in the eighth cervical where unfortunately it is crushed badly. It is this particular process to which the very complete rib, figured on page 33, was found attached. In the type specimen the right diapophysis of the ninth vertebra has been squeezed inward and pressed upward and those of the fifth, sixth, and seventh have been broken off, leaving an indication, however, of their true direction.

Dorsal Vertebræ. The dorsal vertebræ of Gorgosaurus, eleven in number, have a slight gradual increase in size from the first to the last. In the type specimen they, in common with other parts of the skeleton, have suffered from lateral pressure but otherwise they are in a good state of preservation and succeed each other in their proper relative position forming a continuous series. The right rib of each vertebra is present and may be said to be almost in place in each case (Figure 7). Eight of the ribs of the left side are wholly or partially represented but most of them have been displaced (Figure 6). Between the eleventh dorsal vertebra and the first sacral is a vertebra which apparently does not belong to the dorsal series as no rib belonging to it has been found; it is for the present regarded as a lumbar.

The centra of the dorsal vertebræ are evenly excavated on the sides and inferiorly, and have slightly concave anterior and posterior articular surfaces the concavity of which, however, is probably accentuated by the crushing to which the vertebræ have been subjected. The height of the centra exceeds their length and is less than that of the neural arch and spine combined. Their breadth is less than their height, the outline as seen from in front or behind being a broad oval, but as all the centra are abnormally compressed in no case is the true breadth preserved. There is a gradual increase in the size of the centra in passing backward in the series with a corresponding increase in length and size generally of the neural spines. Broad diapophyses, directed outward and upward and backward, are given off from well up on the neural arch. Those of the right side, viz., the lower side of the skeleton as found, are bent upward toward the neural spines whereas those of the

left side in the anterior dorsals have more nearly retained their normal direction. Most of the left diapophyses have apparently been shortened to some extent by pressure and toward the posterior end of the series they are bent downward and distorted. Those of the right side do not appear to have been much affected beyond being thrust upward; in the anterior dorsals their distal ends are seen above the neural spines in a left lateral aspect of the specimen as shown in Figure 6, ns.

In passing backward in the series the diapophyses appear to decrease slightly in length and size generally. These processes are broad at the base, narrow slightly outward, are vertically compressed, and strengthened beneath at midbreadth by a lamina of bone which runs outward toward the distal end of the process, and ends below in the postero-lateral portion of the neural arch. Three right diapophyses viz., those of the fourth, fifth, and sixth vertebræ, appear to be nearly true in shape, and give the following approximate measurements: basal breadth, 95 mm.; distal breadth, 70 mm.; length, 140 mm.

A deep cavity is present in the lateral faces of the centra above their midheight and anterior to the midlength.

The facet for the articulation of the head of the ribs is placed, for the first few ribs at least, on the neural arch near its anterior border. It is very plainly seen in the first three dorsals as shown in Figure 7, at *.

The neural spines increase gradually in length backward in the series, those of the anterior dorsals being less upright than those that follow. Approximately the distance from the top of the spines to the upper surface of the diapophyses proximally in the eleven dorsal vertebræ is as given in the accompanying table of measurements.

Measurements of Dorsal Vertebræ of Type.

Vertebræ.	Length (antero-posterior) of centrum at midheight. Mm.	Distance from top of neural spine to midlength of centrum below. Mm.	Distance from top of neural spine to upper surface of base of diapophysis. Mm.
First	93	276	106
Second	97	278	108
Third	100	288	115
Fourth	102	290	115
Fifth	...	315	120
Sixth	...	...	127
Seventh	...	...	136
Eighth	...	...	140
Ninth	...	295	145
Tenth	134	362	155
Eleventh	150	368	160

The neural spines increase in fore and aft diameter distally. Above their midheight a rugosely surfaced marginal extension of the bone forward, upward, and backward is developed for the attachment of

ligaments. On their side faces the spines are smooth in a narrow axial area sharply defined in front, above, and behind from the marginal zone which latter is horizontally furrowed by grooves of varying depth and distance apart. This marginal extension is slightly less in transverse thickness than that of the axial part of the spine and has an anterior and posterior face rendered rugose by deeply pitted projections and anastomosing channels running irregularly in a general vertical direction, Figure 15. In the type the distal ends of the spines in some of the dorsals

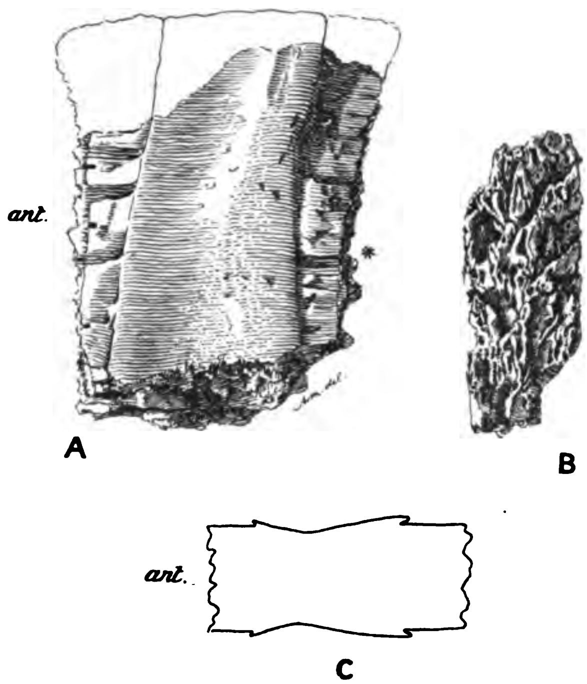

Figure 15. Distal end of neural spine of dorsal vertebra of Gorgosaurus; separate specimen; ½ natural size. Cat. No. 350. A, left lateral aspect; B, anterior view; C, outline of transverse section at *, *ant.*, anterior.

have increased to such an extent in an antero-posterior direction as to approach each other closely and even to effect a union. This distal enlargement of the neural spines occasioned by the development of rugose areas is most developed in the dorsal vertebræ, in the fifth to the ninth vertebra of this series in the type. The spines of the cervical vertebræ show like structural characters somewhat modified, and in the tail they are still less marked. During the preparation of the type specimen, the sandstone matrix between the upper ends of the neural spines of the dorsal vertebræ, more particularly from the fourth to the

last, was found to hold small bony particles, which leads to the belief that there was a slight ossification of the fibrous tissue connecting the spines.

Sacral Vertebræ. The sacrum is entirely hidden on the left side of the type by the ilium.

Figure 16. Pelvic arch of the type of Gorgosaurus; right lateral aspect; $\frac{1}{12}$ natural size. *Il*, ilium; *Is*, ischium; *P*, pubis; SV_1—SV_5, sacral vertebræ.

On the right side the whole of the lower portion of the ilium, including the acetabular region generally, has been shoved upward so as to disclose the coalesced centra of the sacral vertebræ to an unequal extent. Since the drawing reproduced in Figure 7 was made, the right limb of the type specimen has been lifted revealing much that had been hidden by the femur, tibia, and fibula. The centrum of the fifth sacral vertebra is seen and that of the fourth to near its anterior margin which is hidden beneath the pedunculate union of the ilium and ischium (Figure 16). Within the acetabulum the centra of the third and second vertebræ are

revealed, the former for about half its length in front, the latter for nearly its full length. These two centra have been flattened by the head of the right femur, but their junction with each other can be made out a little behind the centre of the acetabulum. The broad contact of the ilium with the pubis covers the centrum of the first sacral from its union with the second to near its anterior end. Five sacral vertebræ are thus revealed and it has been possible to obtain fairly accurate measurements giving the relative length of their centra.

Measurements of Sacrum of Type.

	Mm.
Length of sacrum	690
Length of centrum of first vertebra at midheight (approx.)	138
Length " " " second " " "	128
Length " " " third " " "	130
Length " " " fourth " " "	134
Length " " " fifth " " "	160

The centra of the sacral vertebræ are concave on the sides and beneath. A transverse process connecting with the ilium is seen in the type in the first, fourth, and fifth vertebræ, but that of the second and third is hidden by the ilium. The process of the first vertebra is broad and long and is given off from the upper part of the centrum; in the type it is bent upward and flattened and was seen only when the right femur was moved. Those of the fourth and fifth sacrals are narrower and apparently shorter, and proceed in each case from the middle of the centrum in its upper part; they also are crushed and distorted in the specimen (Figure 7). The lower edge of the surface of contact of the process of the fifth sacral with the ilium is very clearly defined. The upper portion of this surface is seen at *S5* in Figure 39 (inner surface of separate left ilium) and denotes an attachment area of considerable size, as in Tyrannosaurus, in fact there is a general agreement in the position and size of these areas as seen in the separate ilium of Gorgosaurus and the sacrum of Tyrannosaurus as figured by Osborn (op. cit. 1906).

The only other parts of the sacrum visible in the type are the distal ends of the neural spines seen between and at the level of the superior border of the ilia. Near the midlength of the ilia above, the space between these bones has been reduced by pressure to about one-third of an inch, but their distance apart increases both toward the front and rear. The neural spines of the first four sacrals are co-ossified distally, but a space occurs in front of the top of the fifth spine separating it from the fourth. This distal co-ossification of the spines would lead one to expect to find them united at a lower level forming a more or less continuous plate such as is found in Tyrannosaurus.

Caudal Vertebræ. From displaced caudals belonging to the type, determined as the twenty-third, twenty-fourth, twenty-sixth (posterior

end of centrum only), twenty-seventh, and twenty-eighth, and from a tail of another individual (see page 29), we have knowledge of thirty-one caudal vertebræ. Judging from the rate of taper in the more posterior vertebræ it is estimated that five more vertebræ completed the tail giving a full number of thirty-six caudals.

The tail is almost equal to one-half the total length of the animal and must have played an important part in preserving the creature's balance; it was probably dragged for a small part only of its distal length. That the tail was incapable of much flexion is apparent from the greatly increased length of the zygapophyses, and the extent to which they interlock at and behind its midlength. It is probable, however, that the degree of rigidity was not as great as in the tail of the slender and contemporaneous *Ornithomimus altus* Lambe, if to that species properly belonged, as is supposed, the peculiarly shaped caudal vertebræ with greatly elongated, horizontal, and flattened prezygapophyses described and figured by the writer in 1902.[1]

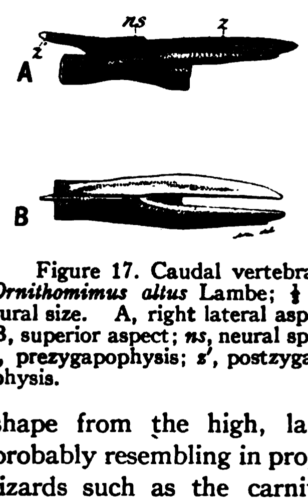

Figure 17. Caudal vertebra of *Ornithomimus altus* Lambe; ½ natural size. A, right lateral aspect; B, superior aspect; *ns*, neural spine; *z*, prezygapophysis; *z'*, postzygapophysis.

In general proportions the anterior caudal vertebræ are stout and about as high as long (Figure 14). In passing backward they soon assume a lengthened, cylindrical form as their diminution in length is less rapid than in height. The neural spines, the transverse processes, and the chevron bones are short, resulting in a tail which, in life, must have been in its proximal half nearly as broad as high, becoming more cylindrical, or circular in cross-section, toward its end, a tail which would be quite different in shape from the high, laterally compressed tail of Trachodon, and probably resembling in proportions that of some of the existing terrestrial lizards such as the carnivorous *Tupinambis nigropunctatus* of South America and the European *Lacerta ocellata.*

In the type skeleton the caudal vertebræ with their chevron bones are in place up to and including the twenty-second. The twenty-third, twenty-fourth, twenty-seventh, twenty-eighth, and part of the centrum of the twenty-sixth were discovered displaced separately in the matrix so that all the vertebræ of the tail in the type are known up to the twenty-eighth inclusive except the twenty-fifth and the greater part of the twenty-sixth.

[1] Geol. Surv., Can., Cont. to Can. Pal., vol. III, pt. II. New genera and species from the Belly River series (Mid-Cretaceous).

A separate specimen, obtained from the Belly River formation on Red Deer river in 1915 and thought to be referable to Gorgosaurus, consists of caudal vertebræ in place in a splendid state of preservation from what are probably the sixteenth to the thirtieth. In this specimen most of the chevron bones are in place including the one that came between the thirtieth and thirty-first vertebræ. Judging from the rate of taper of the centra in this and in the type specimen about thirty-six caudal vertebræ were probably present in Gorgosaurus, and on this assumption the tail is restored to this vertebral length in Figure 49.

In following backward in the caudal vertebral series the centra from being slightly higher than long in the most anterior vertebræ become by gradual transitions considerably longer than high in the more posterior ones, the reduction in height being more rapid than in length. In the twenty-eighth vertebra, the most posterior one found in the type skeleton, the height of the centrum (anterior articular face) to its length is in the proportion of 1 to 2¾ (Figure 18).

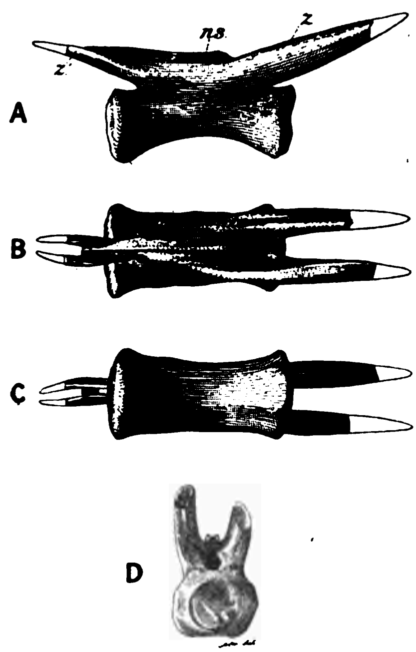

Figure 18. Twenty-eighth caudal vertebra of the type of Gorgosaurus; ½ natural size. A, viewed from the right side; B, from above; C, from below; D, from behind; *ns*, neural spine; *z* prezygapophysis; *z'*, postzygapophysis.

The vertebral centra are concave on the sides and below. With their proportionate lengthening the lower surface becomes more decidedly curved and encroaches more on the side faces. The anterior articular faces appear to be moderately concave, the posterior ones plane or very slightly concave. In the twenty-seventh and twenty-eighth vertebræ, which have not suffered at all from lateral pressure the anterior face has a broad, bevelled peripheral border surrounding a well-defined central concave surface which in the twenty-seventh is markedly concave but in the twenty-eighth is only slightly depressed. In both vertebræ the posterior articular face is bevelled around the edge and plane toward the centre.

The neural spines are short, deep from front to back, thin across, flat on the sides, and end above in a horizontal edge. In those of the

more anterior caudals the height is about equal to the length of the centrum. In most of the spines the upper anterior angle is produced slightly forward giving the anterior face a concave outline in lateral aspect. In passing back, in the tail, the spines decrease in height and. concurrent with the proportionate lengthening of the centra, add to their antero-posterior depth. This increase in depth is attained principally at the distal end where the posterior angulation is produced backward beyond the line of the end of the centrum causing the narrow hinder edge of the spine to face obliquely downward.

Concurrent with the lengthening of the centra, and the antero-posterior extension of the neural spines and chevrons there is a striking prolongation of the prezygapophysial processes. Up to the eleventh caudal vertebra each prezygapophysis (facing inward and upward) is at the end of the process, but at the twelfth the process begins to extend forward beyond the zygapophysial facet and in the vertebræ that follows the prolongation is rapidly increased, each process extending far forward parallel with the neural spine of the preceding vertebra. In the twenty-eighth vertebra the length of the prezygapophysial process is nearly equal to that of the centrum. When the process extends beyond the prezygapophysis the latter faces directly inward and appears on the inner side of the process as a small slightly elevated, oval surface.

The postzygapophyses in the anterior caudals face outward and downward, and occur at the base of the neural spine posteriorly. In following backward the neural spines decrease in height and up to the twentieth vertebra still rise above the level of the postzygapophyses. In the vertebræ that follow, however, the reduced neural spine, sunk to the level of the postzygapophyses, combines with the latter to form a stout backwardly directed, centrally placed process which interlocks with the pair of prezygapophysial processes of the succeeding vertebra. In the eighteenth caudal there is a slight prolongation of the bone backward beyond the postzygapophysis on each side of and past the back termination of the neural spine. This double prolongation, which increases to some extent in the vertebræ following the eighteenth, has the appearance, when viewed from above, of a bifurcation of the central, composite postzygapophysial process. The postzygapophysial articulating facet on each side of this process faces directly outward.

In the anterior caudal vertebræ the prezygapophysial processes are directed upward at an angle of about 35 degrees, but in those that follow they gradually become less inclined. These processes are laterally compressed in a moderate degree, the greater diameter being nearly vertical, in which respect they differ from the much flattened corresponding processes of Ornithomimus, already referred to, with a greater transverse diameter sometimes nearly horizontal (Figure 17). The

transverse processes of the caudals are short, broad, thin vertically, and come to a rather square ending distally. They diminish gradually in size in passing backward in the series and cease with the fourteenth vertebra on which a slight protrusion only of the bone represents the last process (Figure 14).

CHEVRONS.

The chevron bones are intervertebral, short, and change much in shape in passing backward in the series; they begin between the first and second caudal vertebræ and continue to at least the thirty-first caudal. The changes in shape in the chevrons are due principally to a distal enlargement of the bone, which, becoming pronounced first on the posterior face near the beginning of the series, is soon increasingly developed on the anterior face also, forming a keel, and finally, in the hinder half of the tail, is prolonged equally in front of and behind the shaft of the bone (Figure 19). Concurrent with the increasing fore and aft extension of this distal foot there is both an actual and a relative decrease in the length of the shaft which, in its maximum reduction in the smaller posterior chevrons, is little more than a rounded articulating surface, for intervertebral contact, on a constricted neck rising centrally from the foot. The lower edge of the chevrons, as the foot developed, is parallel with the longitudinal axis of the tail. As the depth of the chevrons decreased, in passing backward in the series, so did their antero-posterior distal extension increase; at first deeper than broad, in lateral aspect, they shorten to a "meat-chopper" shape near the middle of the tail, and farther back resemble miniature sleigh-runners in form. This shape in the distal chevrons no doubt indicated that posteriorly the tail dragged, and the extent to which it came in constant contact with the ground can be gauged by the degree of distal expansion found in these bones. The hind feet of Gorgosaurus are those of a land animal, and the form of the tail, and particularly of the chevrons in its hinder half—the bony parts that would be nearest the ground and which would be influenced most by the tail's contact with hard surfaces—also indicate a terrestrial habitat. The tail in Trachodon and its kindred is deep and laterally compressed—suitable for propulsion in water; the chevron bones are long, and slender distally, quite unlike those of Gorgosaurus. When the formation of the tail in the Theropoda generally is better known it will probably be found that the chevron bones resemble those of Gorgosaurus in their main features. In some of the Jurassic Sauropoda, notably in Diplodocus, the "foot" of the posterior chevron bones is proportionately even more longitudinally extended in a horizontal direction than those of Gorgosaurus, a fact strongly in favour of these immense dinosaurs (Diplodocus and allied genera) having been land rather than swamp reptiles.

Measurements of Chevron Bones.

	Mm.
Second Chevron:	
Length (distance from proximal end to distal extremity), ...	227
Breadth (antero-posterior) at midlength.	40
Thickness (transverse) across articular facets.	70
Seventh Chevron:	
Distance from middle of proximal end to middle of lower margin of distal foot	145
Length (fore and aft) of distal foot.	93
Thickness (transverse) across articular facets.	60
Fifteenth Chevron:	
Distance from middle of proximal end to middle of lower margin of distal foot	88
Length (fore and aft) of distal foot.	97
Thickness (transverse) across articular facets.	50
Twentieth Chevron:	
Distance from middle of proximal end to middle of lower margin of distal foot	47
Length (fore and aft) of distal foot.	110
Thickness (transverse) across articular facets.	35

RIBS.

Cervical Ribs. The ribs of the anterior cervicals are short and compact, those of the more posterior ones are relatively large and greatly lengthened.

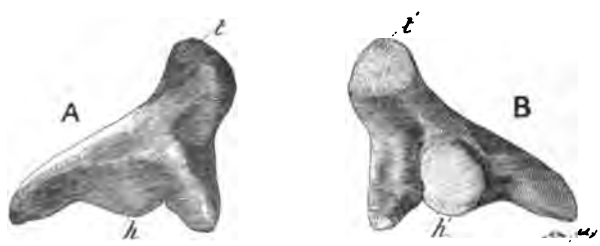

Figure 20. Anterior right cervical rib; ½ natural size. A, exterior view; B, interior view; *h*, capitulum; *h'*, capitu ar facet; *t*, tuberculum, *t'*, tubercular facet.

In the type specimen five cervical ribs and part of a sixth are preserved; all are double headed. One of these was attached to the right transverse process of the eighth vertebra (Figure 21) and the others occurred scattered in the matrix near the neck. Of these latter one appears to be the mate of the one found attached (Figure 7) and two, judging from their correspondence in size and shape, are a pair also and probably belonged to the sixth vertebra (Figure 7). The remaining rib is very short, is from the right side, and was probably attached to the axis or the third vertebra (Figure 20). The rib, represented by the fragments, was on the left side, was also short and is thought to be the mate of the other short rib.

The very short right rib is complete and with it is the distal end of a transverse process to which the facet of the tubercle has remained in contact. This rib (Figure 20) is double headed, triangular in lateral

outline, with an anterior height about equal to its inferior length; it is moderately thick for its size. Its shortness is in marked contrast to the lengthened ribs of the more posterior vertebræ of the neck. The

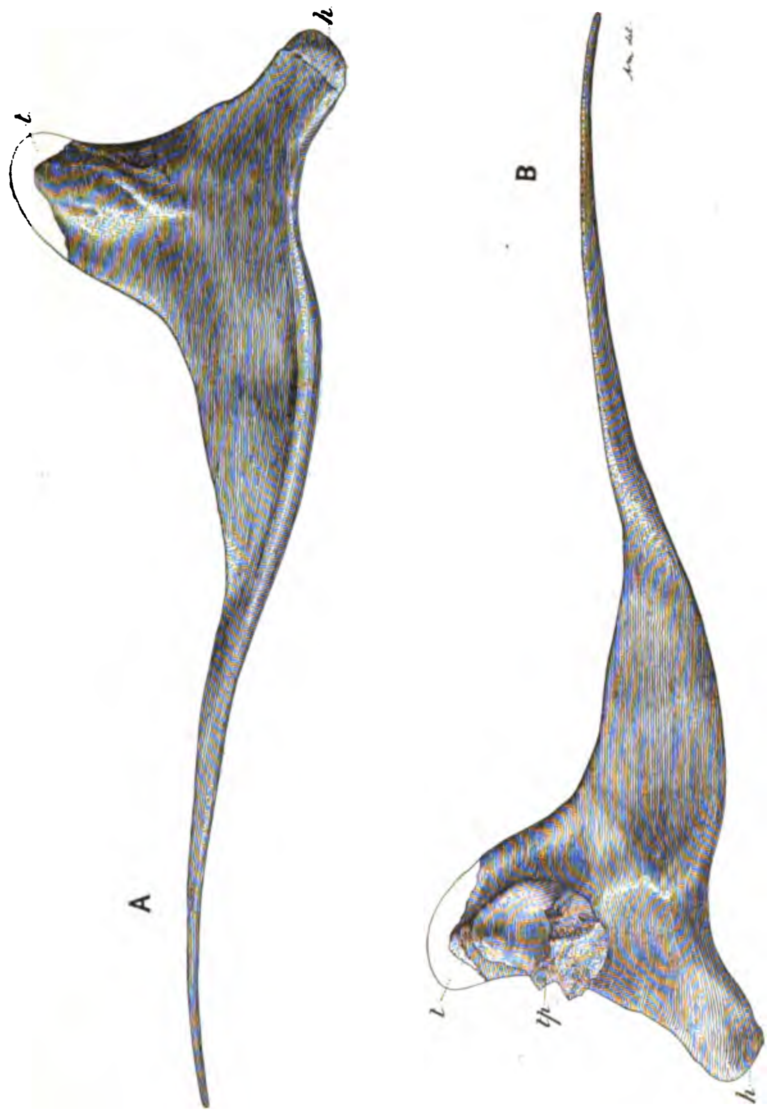

Figure 21. Right rib of eighth cervical vetrebra; ½ natural size. A, exterior view; B, interior view; *h*, capitulum; *t*, tuberculum; *tp*, distal end of right transverse process of eighth cervical vertebra.

portion of the rib extending backward from the head is extremely short; it is narrow, curves slightly downward, is laterally compressed and obtusely pointed behind. There is an extension of the bone forward from the head, from which and from the head rises a broad neck bearing

the tubercle. This forward expansion gives the rib its maximum depth. The tubercular and capitular surfaces of attachment are of about the same size, well-defined, flat, and nearly circular in outline.

Measurements of Right Anterior Cervical Rib.

	Mm.
Length from anterior edge of tubercle to posterior end	107
Anterior depth	77
Inferior length	78
Thickness at upper edge of articular surface of head and at lower part of tubercular surface	14

The rib fragment already referred to, consists of the posterior half of the rib from which the tubercular portion and the lower front extension have been broken off; it was found on the rock surface beneath where the neck partly protruded and had suffered from weathering. So far as a comparison is possible it agrees in size and shape with the specimen shown in Figure 20.

The right rib of the eighth cervical vertebra (Figure 21), which may be considered typical of the more posterior cervical ribs as regards shape, is broad at the base, narrows rapidly backward, and becomes very slender in its distal half length. Anteriorly it is thin and plate-like; the attenuated backward extension retains a slight lateral compression so as to be oval in cross section. The lower anterior angulation forms the head, and in this respect these large posterior ribs differ from the small anterior ones in which the capitular facet is placed farther back. In lateral aspect the front edge of the rib is shallowly excavated, the broad anterior half is deeply concave above and convex below, and the slender distal half bends slightly downward. For a short distance behind the head the lower outline is concave with a thickened border which appears on the inner side of the rib as a ridge above which the bone to the front edge and to the tubercle is thin. A slight inner thickening also occurs as a strengthening ridge directed upward toward the tubercle and bounding the thin anterior area behind. For some distance behind the head the lower border is bent outward and also remains moderately thick. The capitular facet is not clearly defined in the right rib of the eighth vertebra nor is it distinctly marked in the pair which are thought to belong to the sixth vertebra (Figure 7, CR6). When in place on the vertebra the general direction of the rib is downward and backward with the head more advanced than the tubercle.

Measurements of the Right Rib of the Eighth Cervical Vertebra.

	Mm.
Length in a straight line from the lower anterior end to the distal extremity	424
Distance across the anterior border	135
Depth from the tubercle to the concavity of the lower margin behind the head	109
Depth at midlength of lower border	23
Thickness midway between the tubercle and the lower margin	4
Thickness above the lower margin behind the head	15

Thoracic Ribs. The thoracic ribs in Gorgosaurus are eleven in number on either side, and are long, slender, and double headed (Figures 22, 23, and 24). They lengthen from the first to the fourth, or possibly the fifth which is not fully preserved, and shorten rapidly to the eleventh. They are strongly curved near the vertebral end and flatly curved for the remainder of their length downward. The heaviest and strongest part of the ribs is in the neighbourhood of the tubercle which is separated from the head by a long, straight, laterally compressed neck. At and outward for a short distance from the tubercle the ribs have a somewhat inverted L-shaped cross section. With an increasing slenderness downward they become sub-quadrangular in cross section, then sub-circular, and finally narrowly oval near their termination with the greater diameter apparently directed inward and forward.

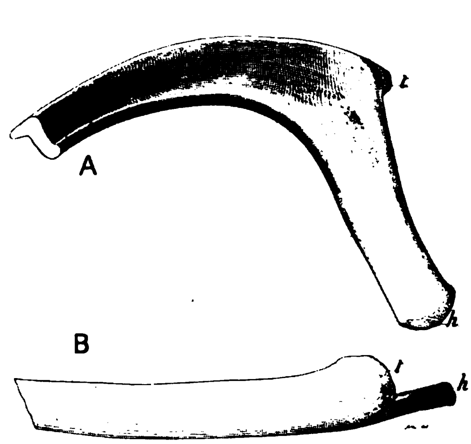

Figure 22. Right rib of third dorsal vertebra of type of Gorgosaurus; ⅛ natural size. A, anterior view; B, superior view; *h*, head; *t*, tubercle.

The laterally compressed neck increases in depth from the head to beneath the tubercle. In its downward and inward direction from the tubercle it inclines slightly forward to articulate with the body of the vertebra. Seen from above the neck is straight; in side view it shows a tendency to bend slightly upward near the head. There is little, if any, increase in the size of the bone at the head whose articular facet is gently convex with a long oval outline of which the greater diameter is vertical.

The tubercle is developed postero-dorsally and extends backward horizontally, its breadth greatly exceeding its depth. It is continued outward along the shaft, for about one-fourth of the distance from the tubercle to the lower end of the rib, as a flange giving the bone a broad upper surface nearly at right angles to the deep anterior face and resulting in the inverted L-shaped cross section which adds greatly to the strength of the rib. Here the dorsal surface is nearly flat from side to side, the anterior face is slightly concave, being shallowly and longitudinally grooved, and the postero-ventral surface is deeply excavated.

With the cessation of the flange and their diminution in depth the ribs become sub-quadrangular in cross section with the dorsal and ventral faces nearly equal and the posterior face broader than the anterior

one, each face being slightly grooved or fluted in the direction of the bone's length with the exception of the dorsal and posterior faces which remain somewhat flat. The upper rib surface is broadest near the tubercle.

The articular facet of the tubercle is convex in an antero-posterior direction, and faces downward, inward, and slightly backward; its depth is about one-fourth its breadth measured along the curve.

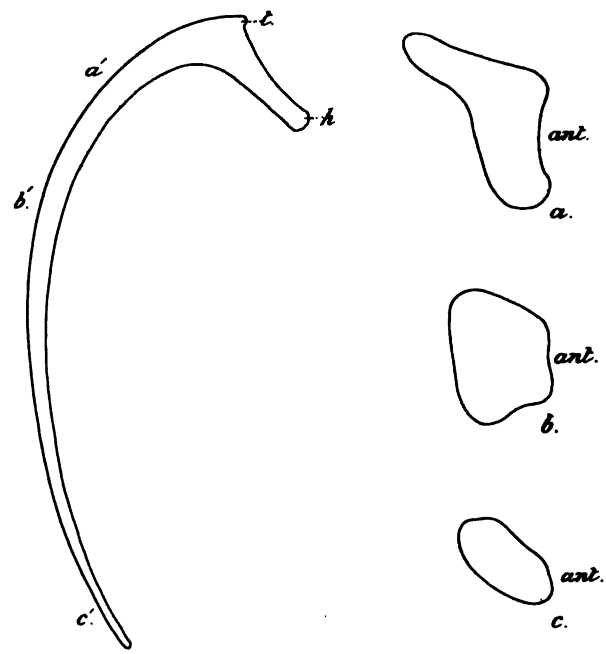

Figure 23. An anterior rib, the third dorsal, of the type of Gorgosaurus; $\frac{1}{10}$ natural size. *a*, *b*, and *c*, outlines of transverse sections of the same at *a'*, *b'*, and *c'* respectively; $\frac{1}{2}$ natural size. *ant*, anterior; *h*, head; *t*, tubercle.

In the type all the right ribs are preserved and articulate with their respective vertebræ or are only slightly displaced. They have, however, been bent backward on each other, but with little distortion of their natural curve (Figure 7). The majority of them have suffered somewhat from pressure and some of them, as indicated in the accompanying table of measurements, are imperfect at the lower end. The second, third, and fourth are complete in all respects. The first and fifth are thought to be complete but their lower ends are hidden by the matrix beneath the abdominal ribs. The tenth and eleventh appear to be fully preserved.

On the left side the greater part of eight ribs and a fragment of the shaft of one are preserved as shown in Figure 6. They are well preserved but all of them have been displaced more or less from their vertebræ.

The changes in the shape of the ribs outward and downward from the tubercle are illustrated in Figure 23 by outlines of cross sections of one of the best preserved of the ribs (the third ?, *, Figure 6) of the left side. This rib has suffered least of all the ribs of the type from distortion and is apparently quite normal in shape.

Measurements in mm. of the Right Thoracic Ribs of the Type.

No. of rib.	Length along outer curve from the tubercle. Mm.	Estimated total length from the tubercle. Mm.
First	860+	865
Second	1143	
Third	1232	
Fourth	1238	
Fifth	838+	1156
Sixth	787+	1073
Seventh	673+	978
Eighth	648+	863
Ninth	622+	711
Tenth	572	
Eleventh	483	

The breadth of the dorsal face of the third right rib, 195 mm. out from the tubercle, is 45 mm., a similar measurement, 143 mm. from the tubercle, in the ninth rib is 41 mm.

At their midlength the dorsal face of the ribs is about 28 mm. broad with a slight diminution in the hinder ones.

The distance in a straight line from the tubercle to the head in the more anterior ribs is about 200 mm.

The length of the first left rib, complete to the lower end, measured along the curve from the tubercle is about 865 mm.

The average height of the head in the more anterior ribs is about 50 mm.

At the time the drawing reproduced in Figure 7 was made the right hind limb completely hid the eighth rib and most of the ninth, tenth, and eleventh. Since then the limb has been lifted, disclosing fully not only as much as is preserved of these hinder ribs but also the anterior end of the ilium and the acetabular region generally.

Abdominal Ribs. In Gorgosaurus abdominal ribs are present forming a cuirass which extends from the sternum back to the distal end of the pubic bones, and whose maximum breadth is equal to about three-fourths of its length.

The ribs occur in a longitudinal series and curve outward and backward from the midline of the cuirass. They alternate to the right and left and overlap at their inner ends. Each rib consists of two parts,

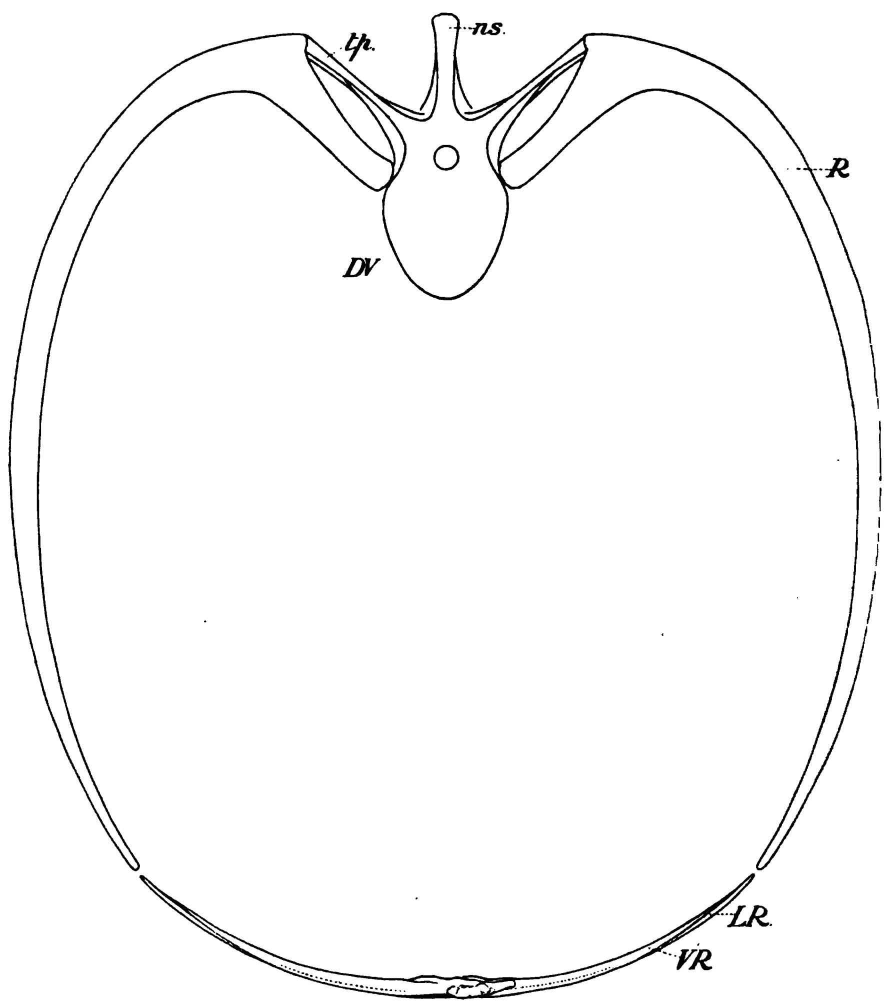

Figure 24. Restored transverse section of trunk at third dorsal vertebra: ⅙ natural size. *D V*, dorsal vertebra; *ns*, neural spine; *R*, left thoracic rib; *tp*, transverse process; *VR*, abdominal rib.

an elongated bone flattened inwardly for the overlap, and a shorter, slender, rod-like bone which is closely applied to the outer end of the larger one. During life the ribs were no doubt bent upward at the outer end but as preserved in the specimen they lie flattened in one plane.

In the type the greater part of the right half of the cuirass is preserved, presenting to view its ventral surface; with it occur a number of overlapping inner ends or heads belonging to the ribs of the left side. The left half of the cuirass had been exposed to the air when the skeleton was discovered and weathered fragments only of the greater part of it were obtained. The number of ribs of the right side, wholly or partially preserved, and following each other closely in regular sequence and in place in the specimen, is seventeen (Figure 25).

Near the sternum was found a displaced rib length (Figure 7, VR1) which is interpreted as being the right half of a double rib formed by the co-ossification of a left with a right hand rib; this double rib is thought to have belonged to the extreme anterior end of the cuirass and to have been No. 1 of the rib series. Among the fragments belonging principally to the left side of the cuirass, is one which appears to be part of another double rib, forming a single median piece, which, judging from its curvature and size was, if not the last, very close to the last of the series. These two ribs, additional to the seventeen found in place, raise the number to nineteen which may be taken as the full number of ribs on either side in the series, although of this there can be no certainty at present; they are introduced as the first and last

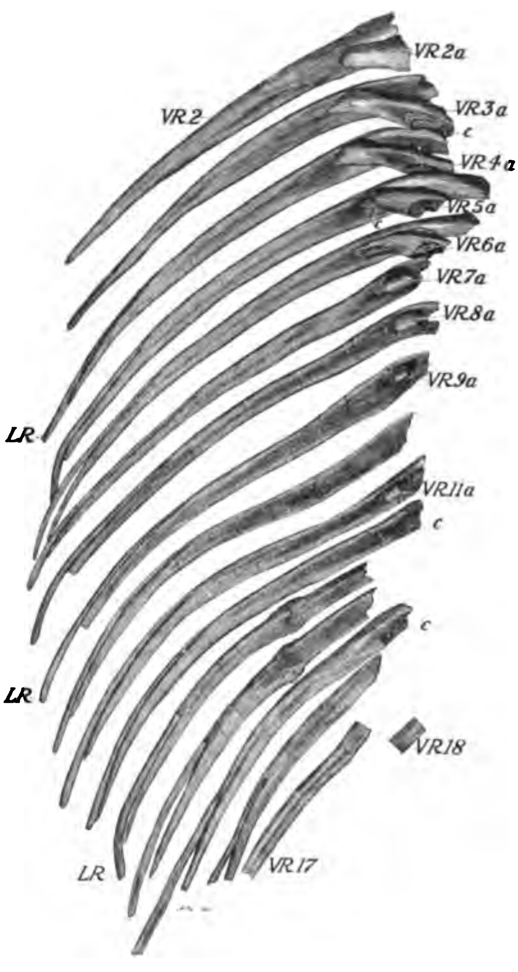

Figure 25. The abdominal ribs of Gorgosaurus as preserved in the type; ventral aspect; $\frac{1}{6}$ natura size. *c*, surface of attachment; *LR*, lateral rib-bone; *VR2-17*, second to seventeenth right rib; *VR2a-10a*, inner ends of left ribs.

ribs in the restoration drawing of the cuirass (Figure 27). Forming part of the abdominal rib series of a carnivorous dinosaur in the Geological Survey collections from the Edmonton formation of Alberta (Red Deer river) are two double ribs, one large and moderately bent with a greatly increased median breadth (fore and aft) due to co-

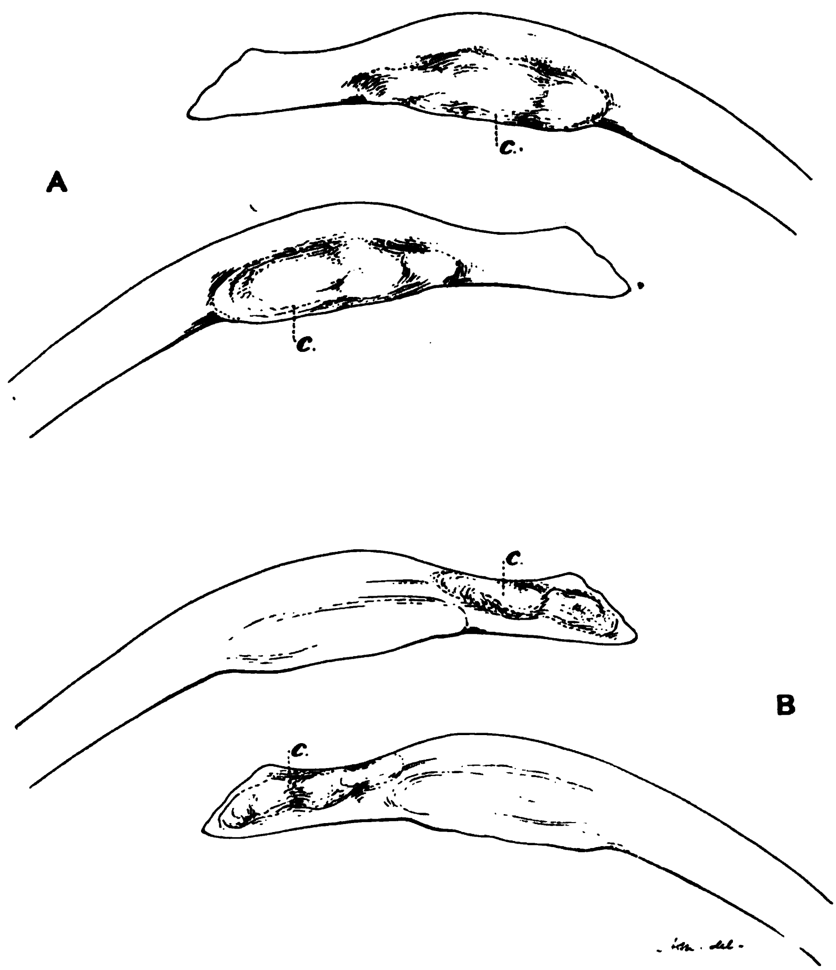

Figure 26. Heads of abdominal ribs of Gorgosaurus to show surfaces of attachment; ½ natural size. A, right and left ribs, ventral aspect; B, dorsal aspect of the same; *c*, surface of attachment.

ossification, the other small and curved rapidly backward from the centre, where there is little evidence of the conjunction of separate bones, the former evidently from the front of the rib series, the latter from the back. Co-ossification of some of the ventral ribs is also found in Tyrannosaurus.

In the type of Gorgosaurus there are preserved in place with the right ventral ribs the inner ends, some complete, others fragmentary, of nine left ribs in the anterior half of the cuirass, disclosing the amount

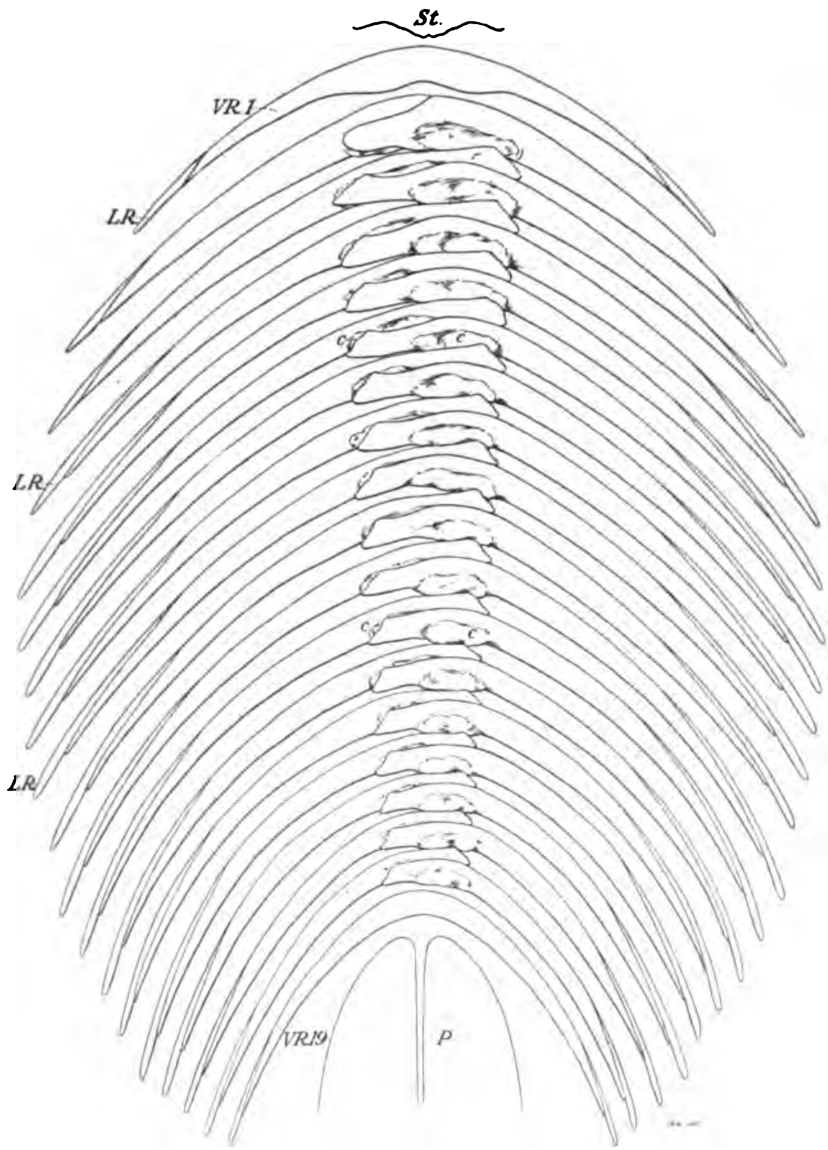

Figure 27. Restoration of abdominal ribs of Gorgosaurus; ventral aspect; $\frac{1}{6}$ natural size. *c*, surface of attachment; *LR*, lateral rib bone; *P*, pubis; *St*, sternum; *VR*, abdominal rib.

and manner of the inner overlap, and the position of the longitudinal middle line of the cuirass throughout its length, assuming that the cuirass was bilaterally symmetrical. With the above data it has been possible, therefore, to reconstruct the entire cuirass of Gorgosaurus as given in Figure 27.

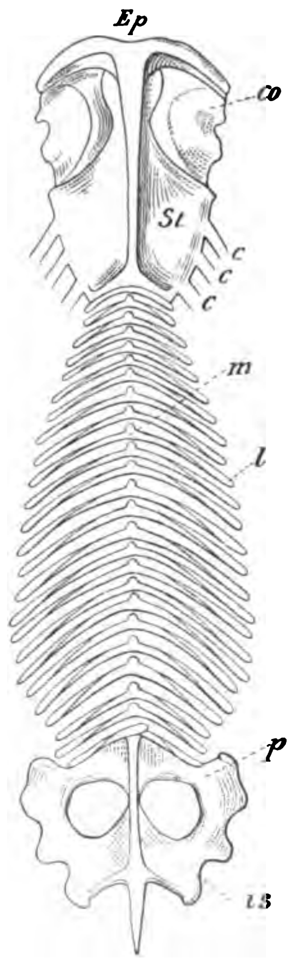

Figure 28. Abdominal ribs of *Sphenodon* (Hatteria) *punctatum* Gray. (After Gagenbaur). *Co*, coracoid; *Ep*. episternum; *Is*, ischium; *m*, *l*, median and lateral pieces of ventral ribs; *P*, pubis; *St*, sternum.

The greatest breadth of the cuirass is slightly in advance of its midlength and the anterior end is broader than the posterior one. As already stated it is probable that there were at least nineteen composite ribs (main piece + lateral one) in each half of the series including in this number the co-ossified half lengths. They increase in length from the first to the fifth. The next two, the sixth and seventh, are about as long as the fifth. Behind the seventh there is a gradual decrease in length to the nineteenth, which appears to have been of about the same length as, or perhaps slightly shorter than the first. In passing backward in the series, however, there is a progressive increase in the backward curve of the ribs, resulting in a considerably diminished breadth in the posterior end of the cuirass as compared with the anterior end.

The central overlap of the ribs decreases in passing backward in the series concomitant with a lessening in their breadth (antero-posterior). In the more anterior ribs the overlap of any two of them is about one-fifth of their combined transverse curve, and this decreases to about one-ninth in the posterior ribs.

In the interlocking of the inner ends of the ribs, the anterior border of each rib reaches beneath the posterior border of the one immediately preceding it from the other side, and each rib is attached by its upper face anteriorly to the lower face posteriorly of the rib in front, rugose surfaces marking the areas of attachment. The upper anterior surface of attachment is situated near the ribs termination; it is thus on the opposite side of the longitudinal midline to which the rib belongs and

consequently the surface to which it is attached on the lower face posteriorly of the preceding rib, is at some distance from that rib's inner termination on the side of the midline to which the rib belongs. Therefore, each rib has two separate rugose surfaces of attachment, one on the upper face near the front border, the other on the lower face near the hinder border (Figures 25, 26, and 27).

The rugose areas of attachment generally have the form of an irregular, elongated oval which is at times broken up into two or three minor surfaces of variable size.

It is probable that there was considerable play between the ribs, obviating a rigidity in the cuirass and securing an amount of flexibility of service probably in connexion with the animal's breathing, and suggestive also of the creature's frequent assumption of positions which brought the abdomen in contact with hard objects such as the ground when resting, or vegetation through which a passage had to be forced.

The ribs are quadrangular in cross section at their midlength, curve evenly backward, and taper gradually to a blunt point. There is a gradual diminution in the breadth (antero-posterior) of the ribs in passing backward in the series. Near their inner ends they become flattened and here reach their maximum breadth with a thin, protrudent posterior edge. The rib heads themselves bend slightly backward, are flat and narrow, and terminate abruptly. As already mentioned, each rib at the median overlap is twisted downward in front so as to bring its anterior border beneath the posterior border of the rib in front and effect an intercostal union.

At the distal end the ribs are grooved infero-anteriorly for the reception of the slender rod shaped bones which lie against them. These latter are more attenuated proximally than distally where they are rather bluntly pointed. Their length is greatest at the midlength of the series where they are about half the length of the ribs to which they are applied and beyond which they project for a short distance.

Whereas in Gorgosaurus and some allied Cretaceous genera a limited number of ventral ribs are co-ossified to form a single median piece supporting a shorter, slender piece at each end, in Sphenodon the majority of these ribs have united in the midline and consist of a central transverse length and two slender outer bones (Figure 28). The ribs of the Cretaceous rhynchocephaloid reptile Champsosaurus have a median and two lateral pieces.

Measurements of Abdominal Ribs in Type.

	Mm.
Length of fifth right rib (exclusive of slender lateral bone) measured along its curve, about	650
Length of sixth right rib similarly measured, about	670
Breadth of second right rib at right end of inner overlap	44
" " third " " " " "	36
" " fourth " " " " "	35
" " fifth " " " " "	35
" " sixth " " " " "	32
" " seventh " " " " "	29
" " eighth " " " " "	29
" " ninth " " " " "	29
Breadth of supposed co-ossified first rib to one side of thickened central part	28
Length of overlap of sixth right with sixth left rib, about	100
Length of slender lateral bone of fifth right rib, approx	240
" " " " " " sixth " " "	277
" " " " " " seventh " "	280
" " " " " " eleventh " "	300
" " " " " " twelfth " " "	282

From the fourth rib back to the tenth the slender lateral bone extends beyond the larger rib piece for about the average distance of 32 mm. In the more posterior ribs the distance decreases backward in the series to about 20 mm. The lateral overlap in the supposed first rib is short, but in the next two or three ribs it increases rapidly to the maximum at the greatest breadth of the cuirass.

STERNUM.

A somewhat distorted, thin, curved plate of bone, with an undulatory, bilaterally symmetrical outline, is apparently the sternum, or the ossified portion of it if that element was originally partly cartilaginous (Figure 29). It is composed of a right and left half in contact at their inner edge, and occurred in the type pressed against and around the centrum of the first dorsal vertebra. Near it, at a distance of a few inches, lay the slender bone described on page 39 and regarded as the right half of a ventral rib from far forward in the series, probably the first.

These supposed sternal bones together, in normal position, form a plate more than twice as broad as long with an upper (interior) rather rough, concave surface, and a lower, smoother, convex one.

The right sternal bone has a moderately concave upper surface and appears to be normal in transverse curvature; from front to back it is rather flat. The left bone of the pair has been pressed inward from the left so that its upper surface is at about right angles to that of its mate instead of continuing to the left the normal, slight transverse curvature of the pair. It has been shifted in position so as to underlap the right one to some extent along the midline of contact, and has also been bent inward at right angles to itself near its outer end.

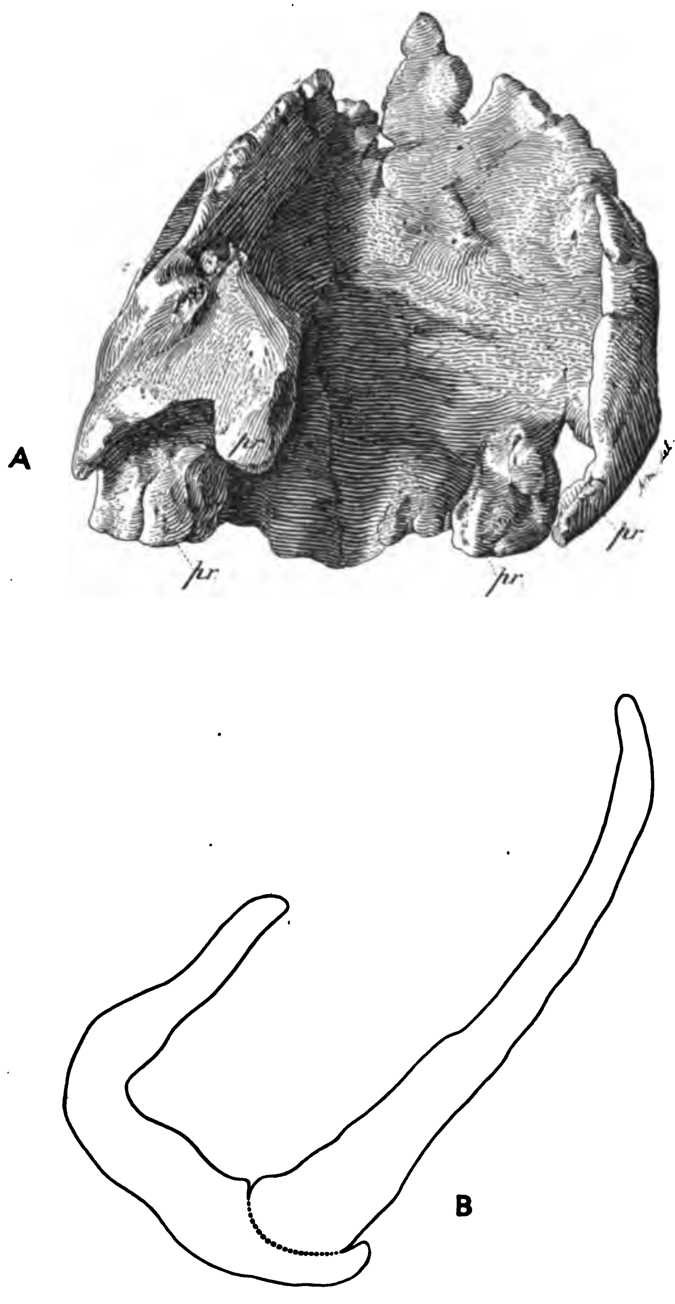

Figure 29. Sternum of type of Gorgosaurus; ½ natural size. A, view from above; B, outline of transverse section; *pr*, process for attachment of sternal rib.

These bones are thickest near the inner line of contact whence they thin slightly outward; the free edges are rounded. There appears to have been a firm attachment of the pair to each other. In each there are corresponding indentations of the edge, one on the lateral back border, and one, rather shallow, behind, as well as some minor emarginations of varying depth and width, principally along the front edge, some of which may be partly due to or accentuated by breaks. In front a surface for contact with the coracoid may be indicated by the outline at *a*, Figure 30. On the outer side of each of the two indentations of the hinder border in each bone, there is a decided projection, conspicuously thick in the inner one, thinner and longer in the outer one, which may mark the position of two pairs of sternal ribs, if indeed the proximal ends of the ribs are not partially preserved.

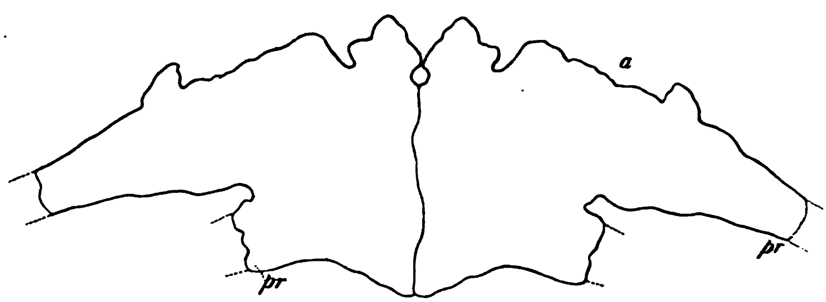

Figure 30. Plan of sternum of Gorgosaurus; ½ natural size. *pr*, process for attachment of sternal rib.

Measurements of Right Sternal Bone.

	Mm.
Maximum breadth along curve of upper surface	170
Maximum length (fore and aft), near inner edge	145
Thickness at middle near inner edge	22
Thickness at midbreadth	14

PECTORAL GIRDLE.

Scapula. The scapula is a long, thin bone, very narrow for the greater part of its length, and expanded at both ends (Figure 31). It consists of an elongated blade and a short lower portion which extends forward abruptly from the base of the blade. The expansion of the blade upward is gradual. In lateral outline the blade is nearly straight in front, slightly concave behind, and flatly convex across the top. In its slender lower half it has an ovoid transverse section narrowing forward, and somewhat flattened on the inner side and behind. It is thickest at its narrowest part, the neck, and thins gradually upward as it broadens.

Below the neck the scapula expands slightly backward, but mainly forward where the bone is thin with a sweeping, semi-circular anterior outline. The posterior border of the lower expansion is short and consists principally of the upper two-thirds of the glenoid cavity, the remainder of the cavity being supplied by the coracoid. The bone ends inferiorly, with a slight anterior contraction in breadth, in a sinuous sutural union with the coracoid.

Coracoid. This bone is relatively large, thin for the most part, and broader than long. In lateral outline it is somewhat four-sided with the lower front angle rounded off and the lower back one produced causing the hinder margin to be concave (Figure 31).

The scapula and coracoid are thickened in the neighbourhood of the glenoid cavity and for a short distance downward from it along the emarginated posterior curve of the coracoid. Elsewhere in both elements, with the exception of the relatively thick neck of the scapula, the bone is thin.

The foramen in the coracoid is not far from the upper edge of that bone and is a little behind its midbreadth. It slants decidedly forward in passing through to the inner side.

The glenoid cavity is shallowly concave, higher than wide, with a well defined peripheral rim. As stated above it is mainly within the confines of the scapula.

The slight curvature which the scapula no doubt had over the anterior ribs is indicated only in the lower part of the blade where the bone has been sufficiently strong to resist the pressure which has flattened the scapula and coracoid practically into one plane, forcing the coracoid away from the inward bend which it naturally had toward the longitudinal midline of the body below. The effect of pressure is strongly marked in the type in the upper portion of the blade where it crosses the ribs (Figure 7). The coracoid was convex externally and concave internally when undistorted, the concavity of the inner surface passing up into the lower expanded part of the scapula, but in the type specimen the flattening of these bones has effaced their natural curvature to a great extent.

The surface of the bone in both the scapula and the coracoid is smooth for the most part but slight striations are present on the exterior of the upper part of the blade of the scapula running in the direction of the length of the bone; also a roughness on the lower border of the backwardly produced infero-posterior angle of the coracoid suggests the position of its probable union with the sternum.

In the type specimen the left scapula and coracoid were not found.

Measurements of the Scapula and Coracoid.

	Mm.
Combined length of scapula and coracoid along the middle of each bone.......	1086
Scapula, length from middle of upper end to middle of scapulo-coracoidsuture..	876
breadth at upper end...	175
breadth at one-fourth of the length up from the middle of the scapulo-coracoid suture...	56
thickness at same point........about...........................	40
Coracoid, length...	210
Length of scapulo-coracoid suture..................................	166

FORE LIMB.

The fore limb of Gorgosaurus is slight and extremely short, its length being a little less than one-fourth of that of the powerful hind limb (Figure 31). In the type specimen it was found above the glenoid cavity having attained that position by the rotation of the limb upward in its socket, the head of the humerus remaining beside the glenoid cavity (Figure 7). The humerus, with its inner surface directed almost backward and its front face nearly outward, lay behind and parallel to the shaft of the scapula. The fore arm was bent downward and backward, the ulna and radius remaining together. The hand had been forced back on the fore arm so as to have the palm facing outward and the digits half closed on themselves. The arm was thus doubly bent, at the elbow and at the wrist, and this position has been retained in the mount, care having been taken to keep the component parts in the position in which they were found relative to each other, sufficient matrix being left to hold them securely in place. The limb is in an abnormally raised and unnatural position, but apart from this the bones are in their proper relative position and their full number is probably present (see carpus, p. 52).

There are two fingers to the manus of Gorgosaurus (Figures 31, 35, and 36) which were interpreted by the writer as being Nos. II and III, and so described and figured by him in the Ottawa Naturalist of January 1914. Prior to the discovery of Gorgosaurus the fore arm and the hand were unknown in any Cretaceous carnivorous dinosaur. Dr. Charles W. Gilmore in his paper "On the fore limb of Allosaurus fragilis[1]" of the Jurassic makes an interesting comparison of the fore foot in Triassic, Jurassic, and Cretaceous Theropods from which it appears that a reduction of the digits began and progressed from the outer side of the hand. In the specialization of the fore limb the greatest known reduction in the size of the limb itself and in the number of the digits was reached in Gorgosaurus. The writer is of the opinion that the two digits previously numbered II and III (original description) are the first and second, as suggested by Gilmore, and they are referred to as such in the present description.

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[1] Proc. U.S. Nat. Mus.. vol. 49, November, 1915.

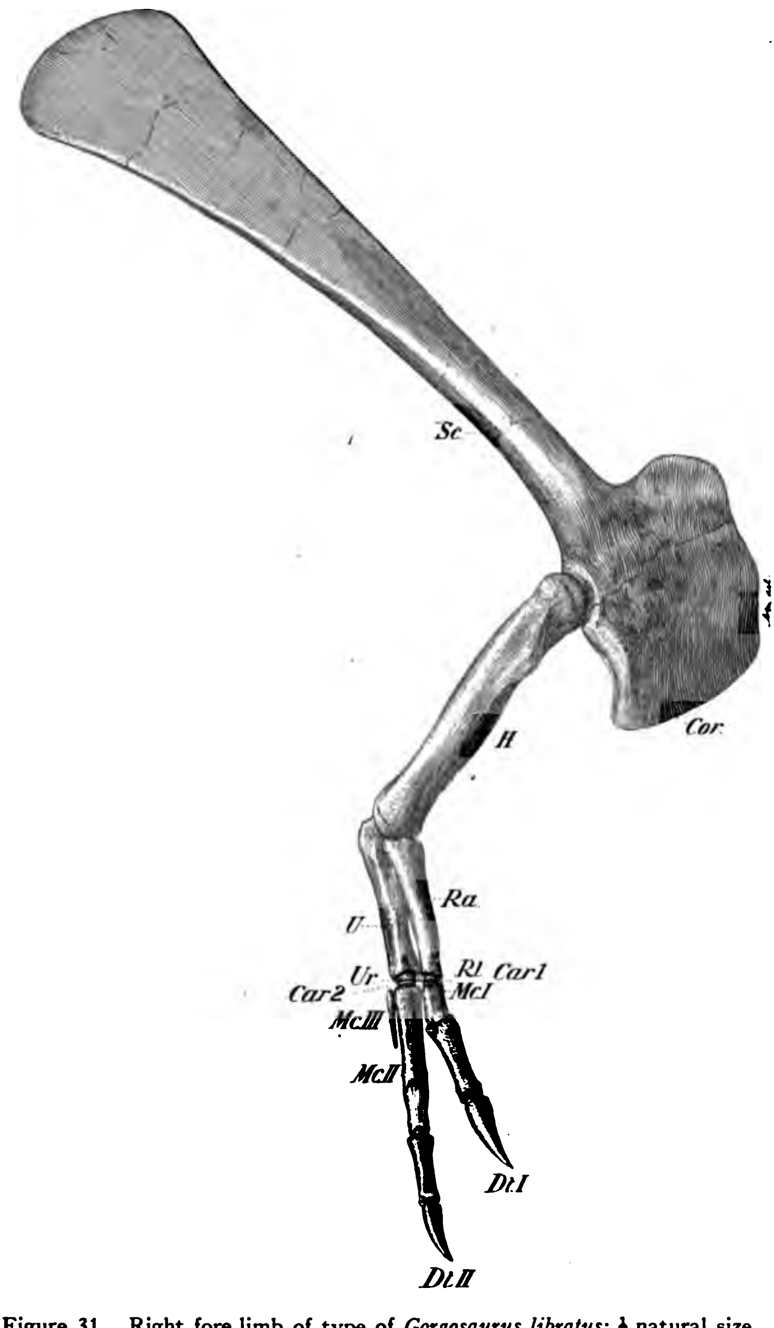

Figure 31. Right fore limb of type of *Gorgosaurus libratus*; ⅛ natural size. *Car*, carpal; *Cor*, coracoid; *Dt*, digit; *H*, humerus; *Int.* intermedium; *Mc*, metacarpal; *Ra*, radius; *Rl*, radiale; *Sc*, scapula; *U*, ulna, *Ur*, ulnare. The coracoid is shown in perspective retreating from the observer.

At the time the description of the right manus of Gorgosaurus was written the sandstone matrix had not been removed from the left side of the specimen and the hope was expressed that the left arm and hand would be found. This hope was, however, not realized except to the extent of recovering some of the parts of that limb viz., the distal half of the radius, fragments which may belong to the ulna, small pieces of phalanges, and phalanges 1I and 2II.

The presence of the complete right fore limb in the type specimen of Gorgosaurus, revealed for the first time the phalangeal formula of the manus of a Cretaceous carnivorous dinosaur, the relative size of the component parts of the limb, and the size of the manus in comparison with the rest of the limb, as before the discovery of Gorgosaurus the humerus only was known in the single genus Tyrannosaurus.

Humerus. The humerus of Gorgosaurus is short and subcylindrical (Figure 31). In its upper half it is decidedly curved with the posterior face concave. The lower half is nearly straight but has a slight bend in the opposite direction. There is a slight constriction of the shaft near either end. The breadth is greatest at the proximal end; distally the greatest diameter is

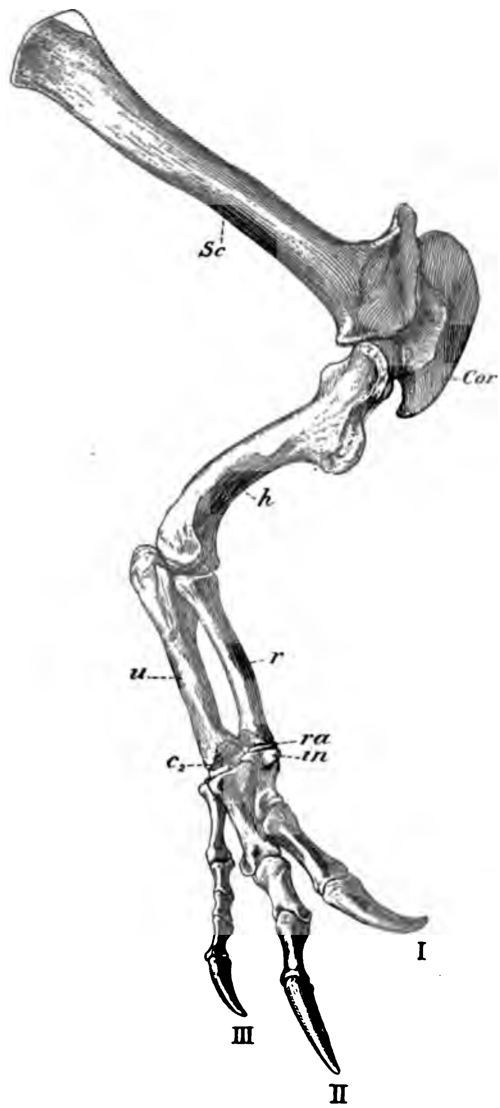

Figure 32. Right fore limb of *Allosaurus fragilis* Marsh (After Gilmore); ⅛ natural size. C_2, carpale two; *cor*, coracoid; *h*, humerus; *in*, intermedium; *r*, radius; *ra*, radiale; *Sc*, scapula; *u*, ulna; I, II, and III, digits one, two, and three.

about equal to that of the shaft at midlength. A high, thin, radial crest, directed forward, runs down the external side of the anterior face from near the proximal end of the bone to about its midlength. In the specimen this crest has been bent down on to the anterior face which, the bone being hollow, has given way and been crushed inward. There is a concavity in the surface of the front face immediately above the distal end. A slight groove across the distal end, in a fore and aft direction, marks the division of the inner, apparently larger, ulnar condyle from the radial condyle on the outer side. The condylar surface of the distal end faces slightly inward in consequence of which the general direction of the forearm would be inward, to some extent. Beneath the head, which appears to occupy the whole of the proximal end, there is a low rugose angulation extending downward for a short distance on the inner side of the posterior face.

Radius. The radius is a short, stout bone a little less than one-half the length of the humerus (Figure 31). It is somewhat quadrangular in cross section with the distal end smaller than the proximal one. The transverse diameter is least a short distance above the lower end. In its lower half the front and side faces are decidedly flattened. It terminates above and below in rather flat articular surfaces, the upper one triangular and somewhat convex with the apex of the triangle pointing inward and a litttle backward, the lower one oblong, with the greater diameter transverse, and shallowly excavated at the centre for the radiale. Distally the front and outer faces are rugosely striated in the direction of the bone's length, also a little more than one-fourth up from the distal end a prominent interno-posterior angulation is roughened for muscular attachment.

Ulna. The ulna is longer than the radius (Figure 31). It is largest proximally where it is triangular in cross section, broadest in front with the anterior face hollowed out for the close approximation of the radius, and angulated behind where a stout olecranon process increases the height of the bone posteriorly. It is narrowest near the lower end and expands little distally. A shallow concavity in and toward the back of the lower articular face denotes the relative position of the ulnare. In its lower half length the anterior face of the bone is flattened.

Both the radius and ulna are somewhat crushed proximally in the type so that measurements taken here are not exact, the transverse diameters being exaggerated and the antero-posterior ones less than normal.

Measurements of the Right Humerus, Radius, and Ulna of the Type.

	Mm.
Humerus:	
Length	324
Transverse breadth at proximal end	55
" " " distal "	64
" " a short distance from either end	50
" " at midlength	55

	Mm.
Radius:	
Length	156
Transverse breadth at proximal end	37
" " " distal "	30
" " " midlength	30
Ulna:	
Length	180
Transverse breadth at proximal end	55
" " " distal "	34
" " " midlength	29

Although differing decidedly in many respects from that of both Allosaurus (Figure 32) and Tyrannosaurus[1] the humerus of Gorgosaurus, as might be expected, resembles more closely that of the Cretaceous Tyrannosaurus of the higher geological horizon.

In comparison with the fore limb of Allosaurus (Figure 32) that of Gorgosaurus is relatively much smaller, the reduction in length being due principally to the extreme shortness of the ulna and radius, the latter bone in Gorgosaurus being less than half the length of the humerus.

Carpus. Five bones are preserved in the carpus in the type, constituting probably the full number of the ossified elements. These bones are the radiale, the ulnare, a probable intermedium, and carpalia 1 and 2. All of these bones are vertically compressed and have rounded outlines (Figures 33 and 35). The radiale and ulnare lie side by side and are larger than the others. The radiale is slightly larger than the ulnare and is almost in place beneath the radius; the ulnare has shifted only a distance of its own diameter from its proper position at the distal end of the ulna. The supposed intermedium is smaller than the radiale and ulnare and lies in front of them in about the same plane but slightly overlapping the radiale; it appears to have been oval in outline with an emargination on one side. The position of this bone suggests its being the intermedium and forming with the radiale and ulnare a proximal row of three. Of the two remaining bones one is the smallest of the five, is bean-shaped, and has not been distorted nor injured in any way; it lies against the front edge of the ulnare and is regarded as carpale 2. The other is in advance of the radiale and is between the intermedium and the upper, outer part of the proximal articular surface of metacarpal I and is probably carpale 1; it is partly hidden, and is crushed and otherwise damaged but it is considerably larger than carpale 2.

Figure 33. Carpal bones of the right manus of the type of Gorgosaurus; ½ natural size. *Car 1-2*, carpale *1-2*; *Int*, intermedium; *Rl*, radiale; *U*, ulna; *Ur*, ulnare.

[1] Tyrannosaurus, Upper Cretaceous carnivorous dinosaur (second communication) by Henry Fairfield Osborn. Bull. Am. Mus. Nat. Hist., vol. XXII, p. 293, fig. 8.

The reduction of metacarpal III and its close contact proximally with metacarpal II renders it probable that a carpale 3 was not developed.

Since the original reference to the carpus of Gorgosaurus was made in 1914, the ulnare has been disclosed raising the known number of carpal elements from 4 to 5; the bone then referred to as the largest of the four is the one now regarded as the radiale.

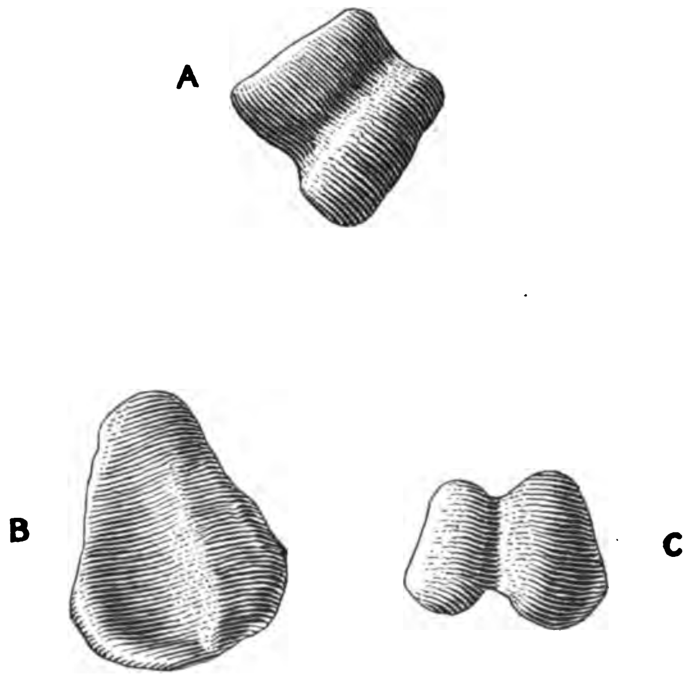

Figure 34. Left manus of type of Gorgosaurus; natural size. A, distal articular end of proximal phalanx of digit I; B, proximal articular end of the same phalanx; C, distal articular end of metacarpal I of right manus of type reversed to represent the corresponding part (missing) in the left manus.

Metacarpus. There are three metacarpals, of which No. I is very short, No. II is double the length of No. I, and No. III is vestigial being represented by a short, slender bone, slightly curved and tapering to its distal end (Figures 31 and 35). Metacarpal I is at the distal end of the radius, metacarpal II has been shifted slightly from the end of the ulna, and metacarpal III lies along the outer side of metacarpal II in the distal two-thirds of that bone's length.

Metacarpals I and II are grooved at the distal end. In the short, stout metacarpal I the groove is narrow, deep, and nearer the inner side, so as to divide the end unequally (Figure 34C), the outer articulating

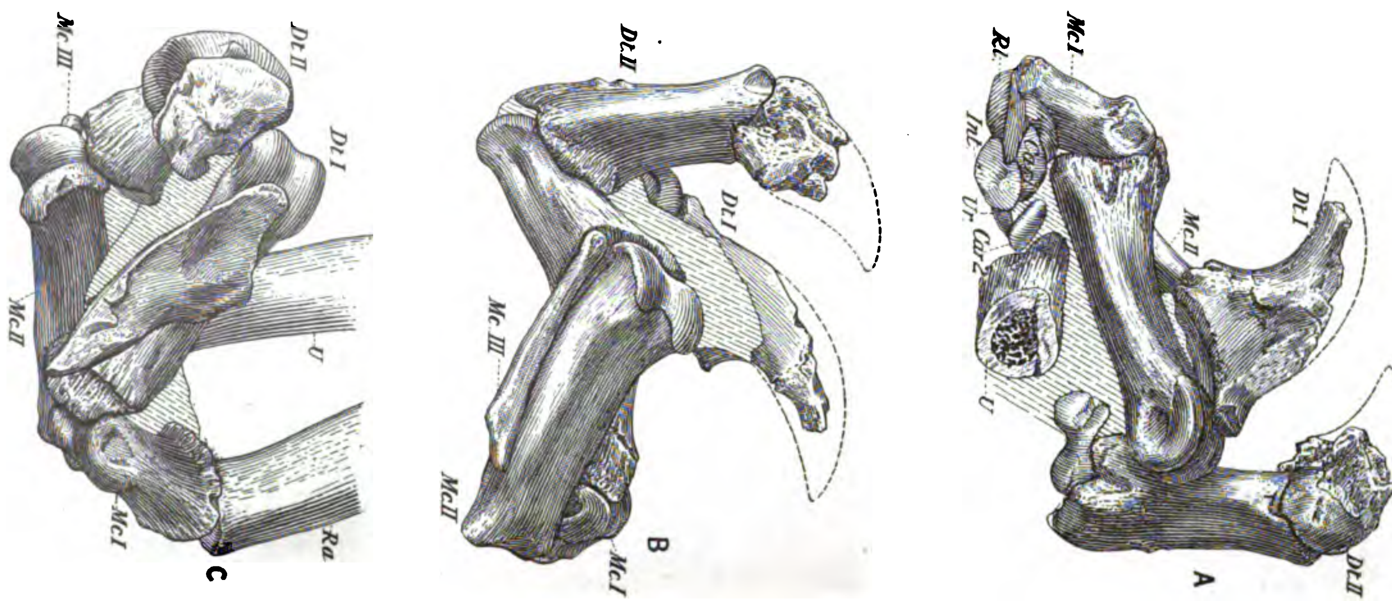

Figure 35. Right manus of type of Gorgosaurus, in the position in which it occurred and in which it has been retained in the matrix; ½ natural size. A, inner aspect; B, outer aspect; C, view from above (the palm upward); *Car*, carpal; *Dt*, digit; *Int*, intermedium; *Mc*, metacarpal; *Ra*, radius; *Rl*, radiale; *Ul*, ulna; *Ur*, ulnare.

facet being the larger of the two and extending farther forward than the other. Both facets curve down and back on to the lower surface of the bone. In the long metacarpal II the groove is broad, shallow, and centrally placed, the convex articulating surfaces running well down beneath the bone. The proximal ends of these two metacarpals are not clearly seen but they appear to have been plane or slightly concave surfaces.

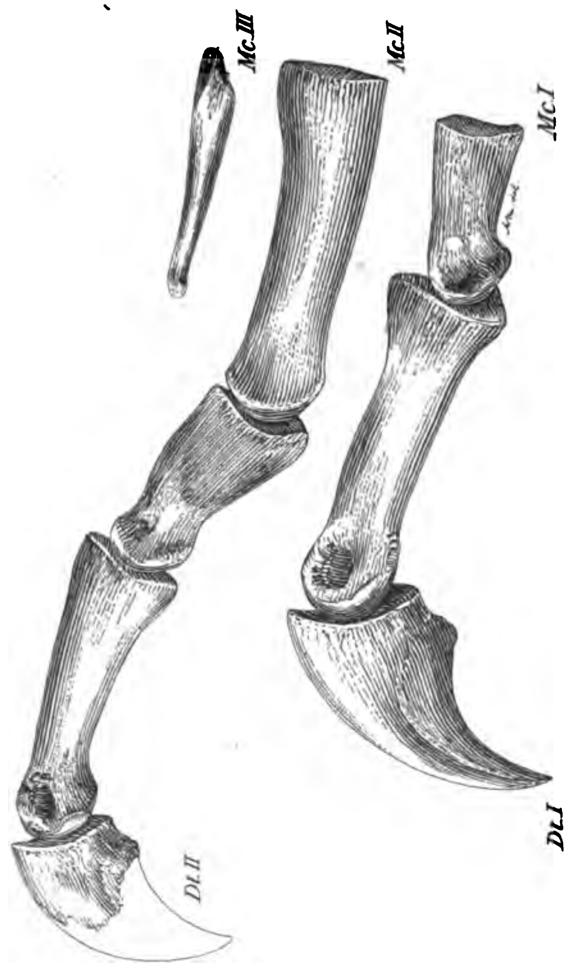

Figure 36. Digits of right manus of type of *Gorgosaurus libratus*; inner aspect; ½ natural size. *Dt*, digit; *Mc*, metacarpal.

Phalanges. The phalangeal formula is 2 I, 3 II (Figures 31, 35, and 36). The two phalanges of digit I consist of an elongated first, and a comparatively large, laterally compressed, curved, and sharply pointed ungual. In digit II the first phalanx is short, the second long, and the distal

98
57 3
8 50/c

one claw-shaped and smaller than the ungual of digit I. In the first phalanx of digit I there is a deep pit on each side of the distal end. In the phalanges of digit II these pits are shallow but more pronounced in the second than in the first. In the corresponding part of metacarpal I circular depressions are present deeper on the outer than on the inner side, but they are not developed at all in metacarpal II.

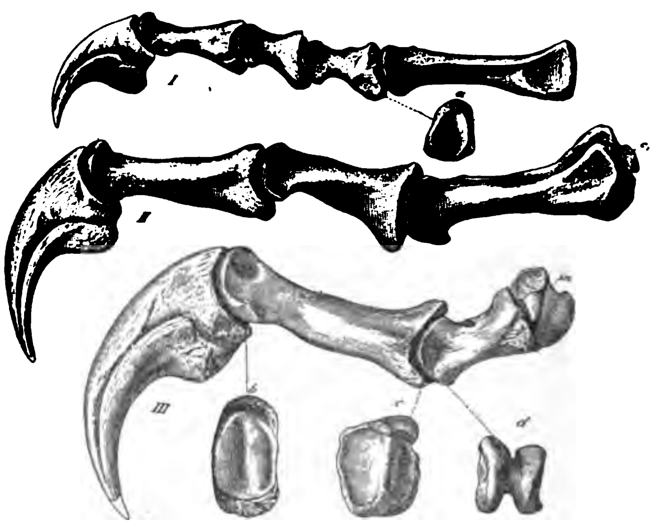

Figure 37. Digits of right manus of *Allosaurus fragilis* Marsh (after Gilmore); ½ natural size. *a*, proximal articular end of the proximal phalanx of digit III; *b*, proximal articular end of ungual of digit I; *c*, proximal articular end of proximal phalanx of the left foot; *C₂*, carpale two; *d*, distal articular end of metacarpal I; *in*, intermedium; I, II, and III, digits one, two, and three.

In the first phalanx of digit I, and in the first and second of digit II, a broad central groove is present at the distal end, and the articulating surfaces face well downward. Proximally a low vertical ridge is developed, dividing the end into equal concave surfaces, except in the case of the first phalanx of digit I where the ridge is oblique running downward and outward across the end of the bone, and dividing it unequally to fit the unequal facets of the distal end of metacarpal I (Figure 34). As a consequence when digit I was rotated downward it was thrown inward with a spreading effect to the hand. A similar construction is noticed by Gilmore in the manus in *Allosaurus fragilis*[1] Figures 32 and 37.

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[1] On the fore limb of Allosaurus fragilis, by Charles Gilmore. Pro. U.S. Nat. Mus., vol 49, 1915.

Measurements of Metacarpals and Phalanges of Type.

	Mm.
Metacarpal I:	
Length	48
Breadth at midlength	22
Breadth beneath, at distal end	26
Metacarpal II:	
Length	98
Breadth beneath, at proximal end	32
" " " distal "	27
Metacarpal III:	
Length	64
Thickness near proximal end	10
First Phalanx of Digit I:	
Length	98
Breadth beneath, at proximal end	30
" " " distal "	25
Terminal Phalanx of Digit I:	
Length along upper curve	95
Depth of articular facet	36
First Phalanx of Digit II:	
Length	57
Breadth beneath, at proximal end	32
Second Phalanx of Digit II:	
Length	83
Breadth beneath, at proximal end	30
" " " distal "	24

PELVIC GIRDLE.

Ilium. The ilium, the largest bone of the pelvis, is more than twice as long as high, and extends farther behind the acetabulum than it does to the front. It is thin tranversely except in the acetabular region where it is relatively heavy and robust. It is much deeper at the front end than behind, the greater anterior depth being due principally to a hooked downward extension of the lower margin. The post-acetabular portion is strengthened on the inner side by a heavy downwardly turned flange running obliquely upward and backward from the ischiadic peduncle giving this part of the bone the appearance of being deeply grooved below longitudinally. In lateral outline the superior border is rather flatly convex, the anterior one irregularly undulating, and the short posterior one evenly rounded.

The bone as a whole has an inclination inward in its upper part, most noticeable above the acetabulum, where over a considerable area the surface is outwardly concave. The superior border for some distance on either side of its midlength is bent inward.

The pubic peduncle is the heaviest part of the bone. From a heavy neck with smooth concave sides and front face it increases in size rapidly downward, providing below an extensive very rugose surface, nearly as broad as long, for the articulation of the pubis. Posteriorly it expands, principally on the inner side, and is shallowly excavated transversely by the broad upwardly curved surface of the acetabulum.

The ischiadic peduncle is slender in comparison with the robust pubic one. It reaches downward to the same extent, and has the same

transverse thickness but is narrow from front to back furnishing an irregularly roughened and relatively small surface for articulation with the ischium.

The iliac surface of the acetabulum, maintaining a nearly uniform breadth throughout its semicircular curve, is slightly narrowed between

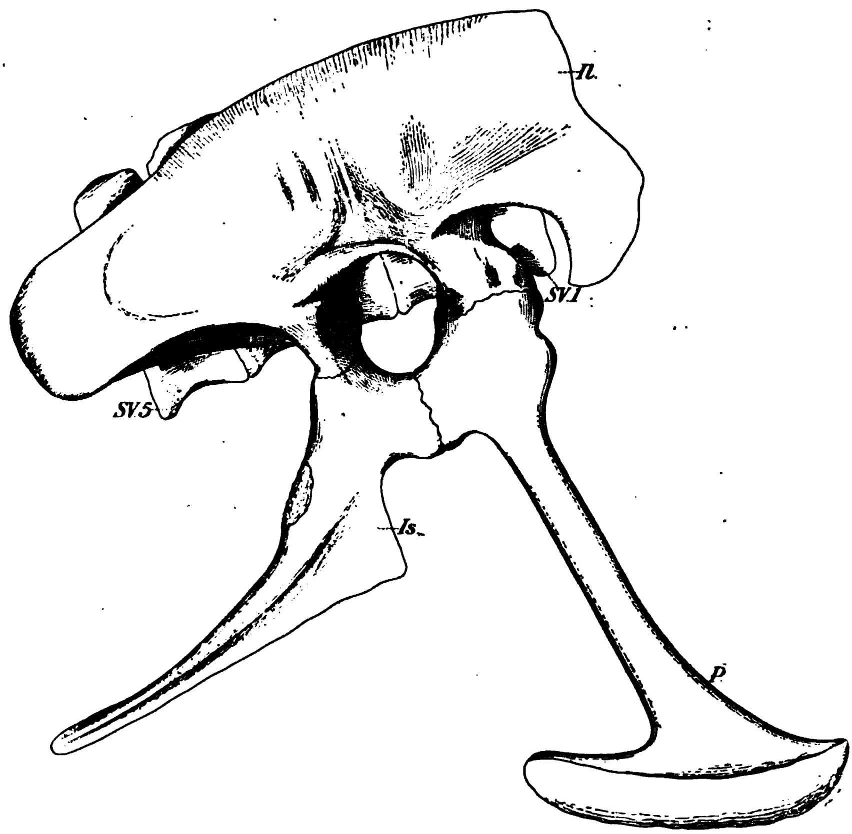


Figure 38. Pelvic arch of the type of *Gorgosaurus libratus*; right lateral aspect; 1/12 natural size. *Il*, ilium; *Is*, ischium; *P*, pubis; *SV*1-*SV*5, sacral vertebræ.

the peduncles; both within and without it comes to a sharp, projecting edge. Anteriorly this surface is decidedly excavated transversely; posteriorly it is flat and faces to some extent outward giving the acetabular opening a slightly backward direction when viewed from without.

For a short distance downward from the superior border along the greater part of its length, the surface of the ilium both internally and externally is striated for muscular attachment, the direction of the

striations being in a general way at right angles to the border and convergent toward the acetabulum. The general external protrusion of the

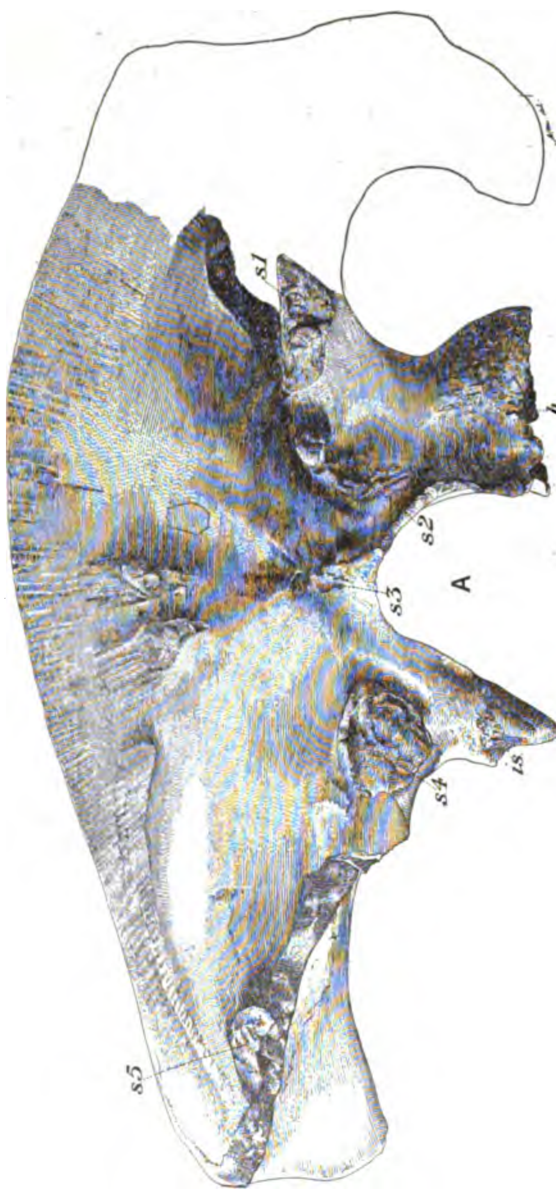


Figure 39. Inner lateral aspect of a separate left ilium incomplete in front, showing the surfaces of contact with the sacrum; ½ natural size. *a*, acetabulum; *is*, ischiadic peduncle; *pb*, pubic peduncle; *s1-s5*, rugose sacral contact areas.

bone above the acetabulum is continued forward as a smooth rounded ridge which merges into and thickens the lower margin of the anterior alar extension behind the hook. Behind the acetabulum the lower

margin is thickened in like manner externally but less conspicuously so, the chief strengthening below being supplied by the downwardly turned inner flange[1] already mentioned.

In the type of Gorgosaurus the ilia, which are in place and conceal the greater part of the sacrum, have not been disturbed with a view to revealing their inner surface. The configuration of the inner side is shown, however, in a well preserved and nearly complete, separate left ilium apparently belonging to this species and figured on page 59.

In this specimen five very distinctly preserved rugose surfaces indicate the position and extent of the contact of the transverse processes of the five sacral vertebræ with the ilium as shown at s_{1-5} in Figure 39. The location of the anterior surface of contact (s_1) and of the two last (s_4 and s_5) agrees with the position of the distal end of the transverse process of sacrals 1, 4, and 5, as seen in the type. Of these roughened areas, the anterior one is above and in line with the front end of the pubic peduncle, and consists of an extensive horizontal surface in combination with a vertical one extending upward and forward. The second area, at a slightly lower level and in line with the posterior face of the pubic peduncle, is smaller, very rugose, and of irregular shape. The third is above the middle of the acetabulum, near its border, and is less definitely circumscribed; at some distance above it are two rugosities, placed side by side, which appear to be an upward extension of this area interrupted by a smoothness of the surface of the bone. The fourth area is rather large and occurs on the upper, posterior part of the ischiadic peduncle. The fifth, also large, is near the posterior end of the ilium. It extended from above the inner strengthening flange, broken off in this specimen, downward to the lower border as seen in the type. These surfaces of contact agree in a general way with those of Tyrannosaurus as indicated by Osborn's figure of the sacrum[2] of that genus.

Measurements of Left Ilium of Type.

	Mm.
Extreme length (38¾ inches)	984
Length in front of middle of upper margin of acetabulum	457
Length behind middle of upper margin of acetabulum	527
Anterior depth	438
Posterior depth	216
Height of upper edge of crest above middle of upper margin of acetabulum	393
Height of upper edge of crest above lower end of ischiadic peduncle	470
Height of upper edge of crest above middle of ilio-pubic suture	457
Extreme outer horizontal width of acetabulum	216

[1] This inner flange, due to distortion, occupies a lower and more outward position than it should in the right ilium of the type (Figure 7). What appears on the outer surface as an "overhanging flange running horizontally at midheight" (original description, p. 7 of this memoir) is best described as the outer, lower posterior border of the bone.

[2] Tyrannosaurus, Upper Cretaceous carnivorous dinosaur (second communication); Bull. Am. Mus. Nat. Hist., vol. XXII, art. XVI, fig. 5.

Measurements of Separate Left Ilium. Cat. No. 2250.

	Mm.
Width of surface of acetabulum—	
Above, at middle of curve	90
Below, anteriorly	97
Below, posteriorly (slightly oblique)	110
Ilio-pubic surface of contact—	
Breadth (transverse)	110
Length (fore and aft)	143
Ilio-ischiadic surface of contact—	
Breadth (transverse)	102
Length (fore and aft)	53
Width of acetabulum, internally	196
Width of acetabulum, externally	140
Thickness of crest—	
At upper edge of rugose surface of attachment of process from 1st sacral vertebra	10
And vertically above the same near upper border	11
At smooth surface above lower surface of attachment of process from 3rd sacral vertebra	4
And vertically above the same near upper border	13
Immediately above surface for attachment of process from 4th sacral vertebra	4
And vertically above the same near upper border	14
At upper edge of surface for attachment of process from 5th sacral vertebra	39

Pubis. This bone (Figures 7 and 38) is expanded proximally to make extensive connexions with the ischium behind and the ilium above. Contracting rapidly it is prolonged downward as a long narrow shaft which expands suddenly below to form a large, backwardly and forwardly extended "foot." The front half of its upper surface is in sutural contact with the ilium, and the hinder half forms the lower anterior quarter of the acetabulum, its contribution to this opening being equal to that of the ischium. The contraction of the bone to form the shaft is gained by an incurve of the anterior border and, more particularly, by a deep emargination of the posterior border, at the lower end of the ischiadic suture, corresponding with the concavity in the outline of the ischium on the other side of the suture. The shaft is straight and retains practically the same breadth downward until it expands rapidly into the distal foot. In its downward direction it inclines slightly forward, meeting the foot, whose axial length is nearly horizontal, at less than a right angle. The foot extends backward to a greater extent than it does forward and is remarkable for its size, being more than twice as long as the maximum breadth of the bone proximally. Its lower outline, in lateral aspect, is broadly rounded. The lower surface, facing obliquely outward, is somewhat convex throughout, defined by a well marked angulation above, and roughened in marked contrast to the smoothness of the shaft.

The pubic bones incline inward from above, come together a little above the midlength of the shaft, and then continue downward in contiguity. Where they meet a prominent rugosity is developed increasing the transverse diameter of the bone. Above the union the shaft is oval

in cross section with the greater diameter fore and aft. Below the rugosity the inner surface of the shaft and of the foot is flattened, and the two bones are closely applied to each other apparently without co-ossification.

Measurements of the Right Pubis of Type.

		Mm.
Extreme length in a straight line from the middle of the iliac suture to the lower, anterior edge of the distal foot		980
Distance along the curve of the pubic contribution to the acetabulum		130
Maximum proximal breadth from middle of sutural contact with ischium to anterior border		220
Breadth of shaft above midlength		66
Thickness (transverse) of same above midlength		52
Thickness (transverse) of same at rugosity		86
Length (fore and aft) of distal foot		563
Depth of same at midlength	about	106

Ischium. The ischium (Figures 6, 7, and 38) is the smallest of the three elements of the pelvis; it is much shorter than the ilium, and is shorter than the pubis by about one-quarter of the latter's length. The bone curves downward and backward with a fairly regular concave posterior border as seen in lateral aspect. It is broad proximally, becomes slender in its distal half, and is narrowly rounded at its termination. Above it contributes to one-quarter of the surface of the acetabulum, and meets the pubis in a suture of considerable length whose direction is vertical beneath the middle of the acetabulum. Posteriorly above its sutural surface for contact with the ilium is deeply concave to receive the terminal edge of the narrow peduncle. Its anterior border, a little below the middle of its proximal half-length, is produced forward in an obtusely pointed expansion which adds greatly to its breadth and beyond which the bone narrows rapidly downward. Bordering the acetabulum the bone is massive, along the posterior margin it is thickened and rounded, but elsewhere it is relatively thin. On the posterior border, a short distance below the iliac suture there is a very distinct, oval, rugose area denoting muscular attachment. The distal ends of the ischia come together for an undetermined distance apparently without co-ossification.

Measurements of Right Ischium of Type.

	Mm.
Length in a straight line from middle of iliac suture to distal end	762
Distance along the curve of the ischiadic contribution to the acetabulum	127
Length of sutural contact with the pubis (vertical)	140
Breadth of sutural contact with pubis across lower surface of acetabulum	48
Breadth from anterior proximal emargination to posterior border	150
Breadth from point of anterior expansion to posterior border	210
Breadth at midlength of posterior border	75
Breadth near distal extremity	43
Thickness near distal extremity	18

In Figure 7 the lower border of the left ischium shows beneath that of the right one, and in Figure 6 the whole of the left ischium is seen with

the upper border of its mate of the right side in view above it. In these two figures both pubic bones also are partly seen.

HIND LIMB.

The great length of the hind limb—one of the notable features of the genus—is contributed to somewhat equally by the femur, the tibia, and fibula, and the much lengthened foot (Figures 6, 7, and 49). The

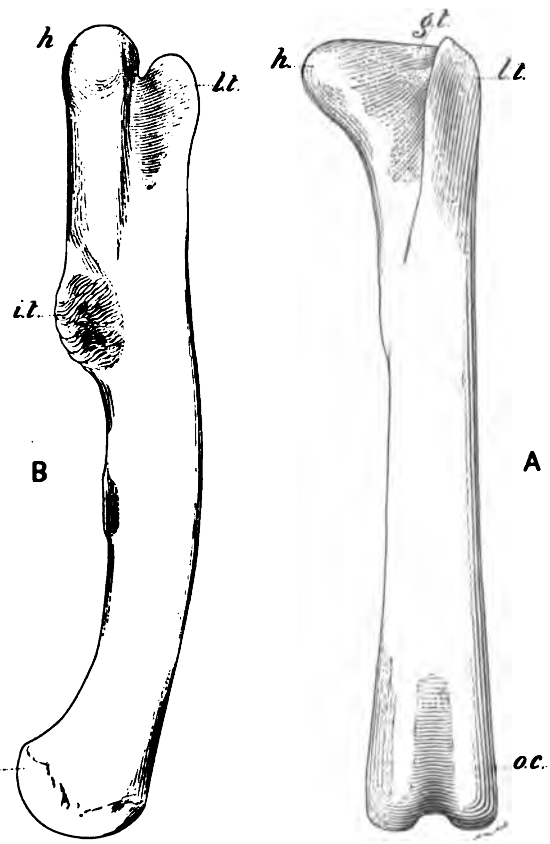
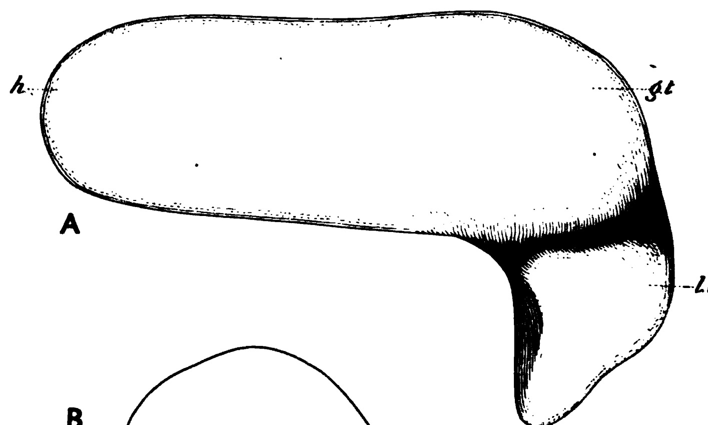


Figure 40. Femur of separate left limb of Gorgosaurus, Cat. No. 350. A, anterior view; B, inner view; $\frac{1}{6}$ natural size. *g.t.*, great trochanter; *h*, head; *i.c.*, inner condyle; *i.t.*, inner trochanter; *l.t.*, lesser trochanter; *o.c.*, outer condyle.

femur is slightly longer than the tibia but not quite as long as the foot (metatarsal III + digit III). The upward trend of the head of the femur threw that bone slightly outward. As the body of the animal was bulky below the hips this obliquity of the thigh bones was necessary to allow of their free forward movement. During locomotion the knee

was considerably bent, the articular surfaces of the knee and ankle indicating the amount of flexure at these joints as represented in Figure 49. The outer condyle of the femur apparently reached lower than the inner one so that the ankle was more under the body and the feet closer together than would otherwise have been the case with an outwardly inclined femur—in other words the animal was bow-legged. A straddling gait is not suggested by the limb bones. The footprints would be in two rather close parallel lines.

A



B

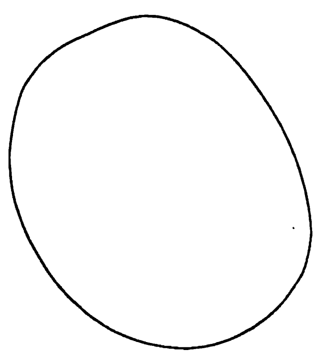


Figure 41. View from above, A, and outline of transverse section of shaft at mid-length, B, of femur shown in Figure 40; ½ natural size. *ant*, anterior; other lettering as in Figure 40.

Femur. This (Figures 40 and 41) the longest and most robust bone of the hind limb has a large head, a strong, thick, forwardly bent shaft, and well developed condyles of which the outer one appears to be slightly the larger. The shaft is nearly circular in cross section at midlength, below which its curvature is greatest.

The head is lengthened inward, and is set almost at right angles to the shaft with a slight inclination upward and ?forward. Its articular surface is well rounded, and there is no indication of a neck. The greater trochanter is on a level with the head whose upper surface is continuous

with that of the trochanter without apparently any intervening demarcation. The lesser trochanter is conspicuous on the anterior border of the outer face and rises nearly to the height of the greater trochanter with a free upper end. The inner trochanter is well developed and occurs rather high up on the inner face posteriorly a short distance above the midlength of the bone. A shallow depression extends upward for some distance on the anterior face of the shaft from between the condyles, and on either side of the depression the bone is angularly protrudent. The condyles are extended backward, and the intercondylar groove is deep. A short distance below the midlength of the bone, and in line with and considerably below the inner trochanter there is a small rugose area for muscular attachment. The general surface of the shaft is smooth.

The posterior face of the femur at its proximal end is broadly rounded from the articular surface of the head outward. The anterior face from the lesser trochanter inward is concave. The lesser trochanter is triangular in cross section, narrowing to the front where it ends in a free vertical edge directed inward and forward. It has a flat antero-external surface which rounds rapidly backward to the broad convexity of the posterior surface of the bone. Its inner surface is concave in continuation of the broad transversely concave surface of the anterior face. The upper end of the lesser trochanter is separated from the greater trochanter by a deep, narrow groove running in an interno-external direction.

Tibia. The tibia (Figures 42 and 43) is slightly shorter than the femur and is expanded at both ends, distally in a transverse direction, and proximally from back to front to a less extent. The bone in lateral aspect is rather straight in its upper half length, and bends slightly forward below the middle. The shaft is flattened antero-posteriorly so as to be broadly oval in cross section in its main mid-portion. On the upper surface two small tuberosities, separated by a shallow groove, slightly overhang the posterior face. Proximally a heavy process, for muscular attachment, is developed from the inner half of the front face. It extends forward with a curve outward and greatly increases the antero-posterior thickness of the bone at the upper end. It comes to a vertical angulation in front, is convex on its inner side and concave externally, the convexity being continued outward in the remainder of the front face of the bone.

A large cnemial process directed outward and slightly forward occurs on the antero-external border. It is laterally compressed, conspicuously protrudent, and comes to an irregular vertical edge with a rugose anterior surface and a smooth, concave posterior one. It bounds outwardly the lower end of the upper concavity of the front face and is in advance of the fibula when that bone is in position. Following downward from the cnemial process there is a decided angulation which defines

anteriorly a narrow external flattening of the shaft marking the downward contact of the fibula. Distally the tibia in its expansion thins laterally, and is transversely concave anteriorly and convex posteriorly. Antero-inferiorly it is transversely concave at midbreadth and convex to either side, fitting closely to the astragalus with which it apparently becomes conjoined. The posterior face distally is broadly angulated in a vertical direction on the inner side of its midbreadth, the face of the bone on each

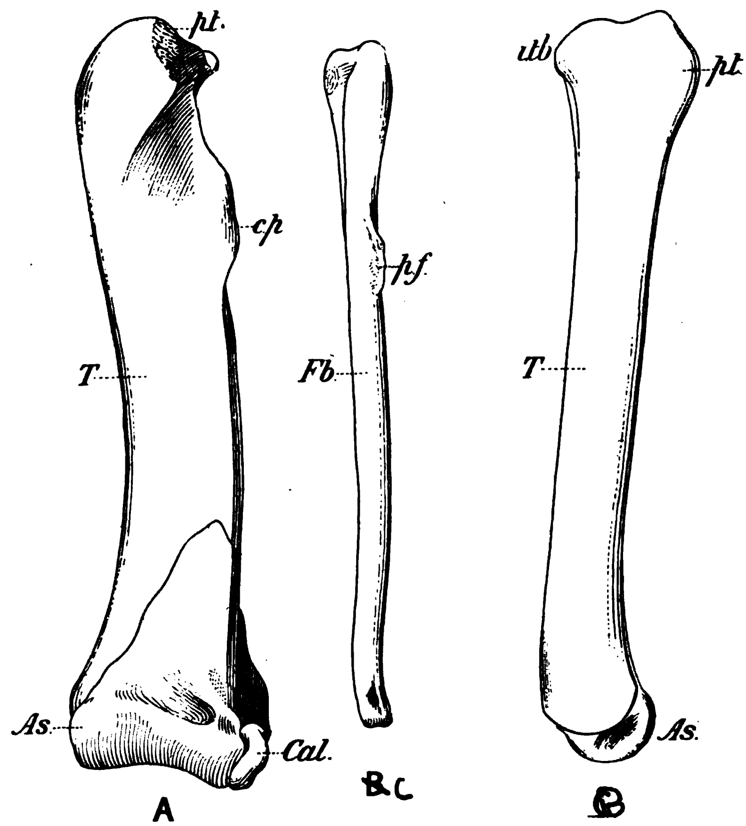


Figure 42. Tibia and fibula, with astragalus and calcaneum, of separate left limb of Gorgosaurus, Cat. No. 350. A, anterior view of tibia; B, inner view of same; C, anterior view of fibula; ⅛ natural size. *As*, astragalus; *Cal*, calcaneum; *c.p.*, cnemial process; *Fb*, fibula; *i. tb*, inner tuberosity; *p.t.*, process of tibia; *p.f.*, process of fibula; *T* tibia.

side being flattened with a slope forward to the lateral border. Outwardly the bone is extended behind the calcaneum and the distal end of the fibula. Distally the anterior face is transversely concave in its contact with the astragalus, becoming flat where it fits against the

posterior faces of the calcaneum and the fibula. Proximally a small rugosely striated area on the external posterior border of the outer tuberosity marks the contact of the upper end of the fibula at this point.

In Gorgosaurus, as well as in Dryptosaurus (Albertosaurus) of the Edmonton formation of Alberta, the tibia has a breadth below equal to

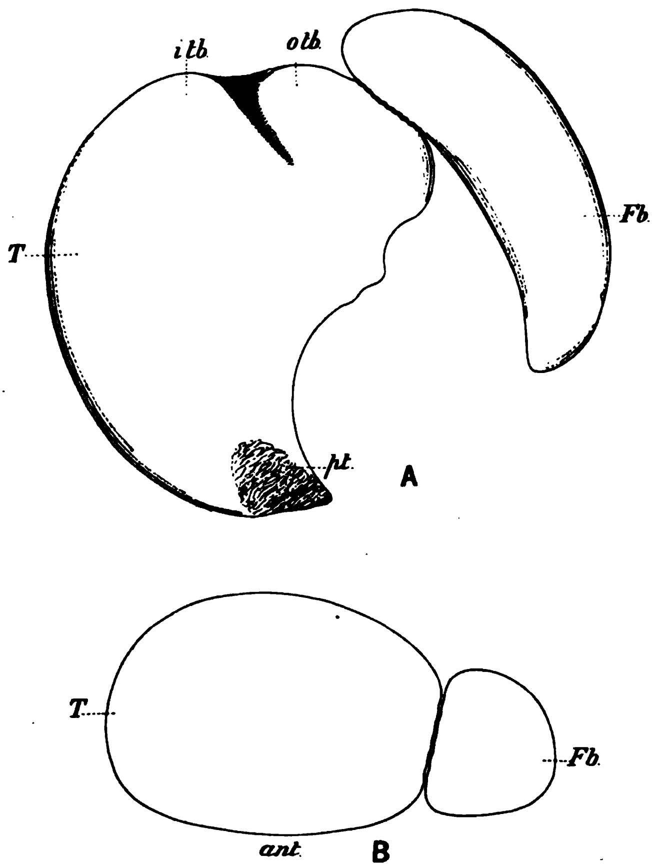


Figure 43. View from above, A, and outline of transverse section of shaft at midlength, B, of tibia and fibula shown in Figure 42; ½ natural size. *ant*, anterior; *o.tb*, outer tuberosity; other lettering as in Figure 42.

the combined breadths of the astragalus and calcaneum. In *Ornithomimus altus* the tibia is equal to the astragalus only in breadth and does not extend behind the calcaneum.

Fibula. The fibula (Figures 42 and 43) is a long, nearly straight bone with a slender shaft increasing slightly in diameter from below upward. It is small distally and expands antero-posteriorly at its

proximal end. It is closely applied to the tibia for the greater part of its length, is in contact also with the ascending process of the astragalus, and rests below on the calcaneum in advance of an extension outward of the border of the tibia. Its length is slightly less than that of the tibia. The chief noticeable features of the fibula are its slenderness and its very close lateral application to the tibia and astragalus.

Proximally the bone is subcrescentic in transverse outline, concave on the inner side and broadly convex outwardly. The narrow upper surface is flat. At midlength the shaft is subcircular in cross section, rounded except on the inner side which is broadly flattened, the antero-posterior diameter being the greater. The distal end is convex below, and subovate in cross section narrowing backward. Proximally the inner face is antero-posteriorly concave to near its upper termination where the bone suddenly thickens to a flat, or only slightly concave surface flush with the front and back borders of the bone. On the anterior face, at a distance of one-third of the length of the bone from the upper end, a small protrudent rugosity is developed which, when the fibula is in place, constitutes a downward continuation of the cnemial process of the tibia. At the upper end a small roughened surface is present on the inner face posteriorly marking the application of the bone to the outer tuberosity of the tibia. The inner face of the bone is flattened throughout its length except in its expanded concave portion above. When in position the fibula articulates with the tibia posteriorly above, is free for a short distance above the cnemial process, then passing downward behind and closely against that process it is applied externally to the shaft of the tibia and distally lies against the flattened outer edge of the ascending process of the astragalus and the front face of the tibia externally.

Measurements of the Femur, Tibia, and Fibula of the Type.

	Mm.
Femur (left), length . . . about	1040
Antero-posterior diameter of shaft at midlength	136
Tibia+astragalus (left), length	1000
Fibula (right), length	883
Antero-posterior diameter at proximal end	180
Antero-posterior diameter of shaft at midlength	47
Interno-external " " " "	37
Antero-posterior diameter at distal end	50

Measurements of the Femur and Tibia of Separate Left Hind Limb, Cat. No. 350.

	Mm.
Femur, length	930
Distance from inner surface of head to outer surface of greater trochanter	242
Antero-posterior diameter of shaft at midlength	133
Circumference of shaft at midlength	394
Tibia, length	842
Antero-posterior diameter of shaft at midlength	93
Transverse " " " "	140
Length including astragalus	882
Maximum transverse diameter at proximal end	164
Maximum antero-posterior diameter at proximal end	183
Transverse diameter at distal end	266

Tarsus. The ossified elements of the tarsus are five in number, viz., the astragalus and calcaneum forming a proximal row, and three flattened bones in a distal row.

The construction of the tarsus seems to be very similar in all essential particulars to that of the smaller and relatively slender *Ornithomimus altus* Lambe, from the Belly River formation of Red Deer river, Alberta,[1] in which there are three tarsalia forming a distal transverse row.

Astragalus. The astragalus (Figure 42) is very large in comparison with the other bones of the tarsus and consists of a main portion curving from beneath to the front of the distal end of the tibia, and a broad ascending process applied to the anterior face of that bone. It is higher than broad, thin below in comparison with its breadth, and much thinner in the ascending process. The main lower portion is tumid anteriorly and inferiorly on either side of a wide constriction so as to have somewhat the shape of an hour glass when viewed from the front. The constriction is most pronounced nearer the fibular than the inner side in consequence of which the inner tumidity is broader and less steeply sloped than the other. Its upper surface, on which the distal end of the tibia rests, is concave in an antero-posterior direction, and concavely excavated transversely on either side of the midbreadth where it is evenly and broadly convex. Its posterior border is overhung by the tibia. The surface against which the calcaneum fits is concave and larger than the free inner surface which is flat or only slightly concave.

The ascending process is nearly as broad at the base as the main portion from which it springs. It is triangular in outline in anterior aspect, narrowing rapidly upward, mainly from the inner side, and becoming very thin above. Its outer edge is rugose and flattened for the close approximation of the fibula in continuation downward of the fibular contact surface on the shaft of the tibia. The anterior face is set back from the rotund lower portion of the bone, is conspicuously excavated at the middle below, and is further defined by a well marked groove traversing its base from side to side.

That the main portion of the astragalus became co-ossified with the tibia is probable. In *Ornithomimus altus* the union of these two bones is well illustrated by the distal end of a left tibia, from the Belly River formation (Geological Survey, Cat. No. 199), to which the astragalus is attached by partial fusion. In this specimen there appears, however, to have been no co-ossification between the ascending process of the astragalus and the tibia.

Calcaneum. This bone (Figure 42) is closely applied to the outer side of the lower portion of the astragalus in advance of the tibia. It is narrow transversely and longer than high. In lateral aspect it is flattened

[1] Geol. Surv., Can., Cont. to Can. Pal., vol. III, quarto, pt. II, 1902, p. 50, fig. 11..

above and behind, is deepest toward the back, and is rounded below and in front in a nearly semicircular curve. Its upper surface is short, broadest behind, and excavated to receive the distal end of the fibula. Behind its articulation with the fibula it meets the tibia in a surface which slopes evenly downward and backward, with a slight inclination inward, becoming narrower below. The inner face is convex in its contact with the astragalus. The combined lower and front surface is convex transversely and conforms to the curve of the astragalus. The outer, free surface is flat or slightly concave with a raised front border; anteriorly its separation from the rounded surface of the front end is accentuated by a well marked groove passing downward behind the marginal ridge. The inner and posterior borders of the lower surface are extended to definitely underlap the astragalus and tibia respectively.

Measurements of the Astragalus and Calcaneum of Separate Left Hind Limb, Cat. No. 350.

	Mm.
Astragalus:	
Maximum, height .... about	300
Breadth, below	208
Distance from anterior face of outer rotundity to posterior border	100
Distance from anterior face of inner rotundity to posterior border	93
Distance from anterior face of median constriction to posterior border	80
Calcaneum:	
Maximum length (antero-posterior)	109
" height	73
" breadth, above	43

Distal Tarsalia. The three distal tarsals, Nos. 2, 3, and 4, are flattened, somewhat disc shaped bones, occurring in a transverse row above metatarsals, II, III, and IV. In the type specimen they have been subjected to pressure which has caused a certain amount of distortion and displacement so that it is difficult to determine their true shape and exact normal position, especially as in the two limbs the pressure has not affected them equally.

So far as can be judged from available data, these tarsals were of nearly equal size, were flush behind with the posterior border of the upper surface of the metatarsals, but in the case of Nos. 2 and 4 apparently did not reach fully to the anterior border of metatarsals 2 and 4. Tarsale 3, applied to the reduced proximal end of metatarsal III, overlapped metatarsals II and IV on either side. Nos. 2 and 4 covered the greater part of the upper end of their respective metatarsals.

In the left foot of the type tarsale 2 is not resting on the top surface of metatarsal II but, with the flexion of the ankle, seems to have left that surface and to have been crushed against the inner anterior rotundity of the astragalus (Figure 7, tar. 2). Tarsale 3 is over metatarsal III and extends laterally for a short distance over metatarsals II and IV. Tarsale 4 covers the greater part of metatarsal IV; it is thickest, apparently normally, at the back externally and thins toward the front and inwardly.

In the other foot of the type two of the distal tarsals are preserved, viz., Nos. 3 and 4, but No. 2 is missing. The two preserved are much distorted and appear as represented in Figure 44 with their antero-posterior diameter reduced and with a decided displacement in the case of No. 3 inward.

In a hind limb, presumably of Gorgosaurus, obtained from the Belly River formation on Red Deer river in 1915, the three of the distal elements of the tarsus are preserved.

The distal tarsals in Gorgosaurus appear to have been soft bones and it is probable that cartilage entered largely into the formation of the ankle joint.

Metatarsus. The metatarsus of Gorgosaurus is composed of five bones of which all are present and in place in both feet in the type. Metatarsals II, III, and IV (Figures 44 and 45) are the principal, fully functional ones, are conspicuously elongated, and fit closely against each other throughout their length except for a short distance distally where II and IV bend away from No. III leaving its distal end free, the separation being best seen in a posterior view. Metatarsal I is greatly reduced and is represented distally only by a very short bone which is attached to the inner side of the posterior face of No. II at the latter's midlength. Metatarsal V is vestigial and consists of a slender, short bone representing the proximal end only of this element. Reference to the composition of the metatarsus of Gorgosaurus was included in the writer's original description of the genus and species published in 1914.

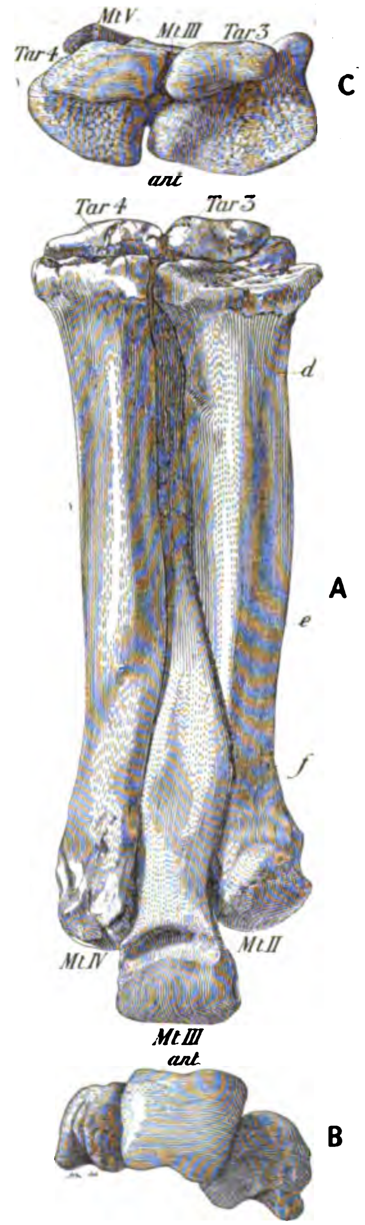


Figure 44. Metatarsals II, III, and IV of the right foot of the type of Gorgosaurus; ⅛ natural size. A, anterior view; B, lower aspect; C, upper aspect; *ant*, anterior; *d*, *e*, *f*, position of transverse sections given in Figure 45; *Mt*, metatarsal; *Tar*, tarsal.

Metatarsals II, III, and IV are principally notable for their length and the manner in which they are closely applied to each other, as in the extremely slender *Ornithomimus altus* Lambe, in which these elements have apparently reached a maximum of elongation. Nos. II and IV are robust bones, with heavy shafts, and expanded proximal ends. Metatarsal III is considerably longer than Nos. II and IV, and extends for some distance beyond them distally, at the same time reaching farther forward; No. IV is slightly longer than No. II. Metatarsal III is attenuated above and attains its greatest size in its lower half length, the distal end being larger than that of either of the other two. Proximally it is crowded backward between Nos. II and IV and is here seen only when viewed from behind. Passing downward between II and IV, and visible to about the same extent in both an anterior and posterior aspect of the metatarsus, it gains a more forward position in its distal half, II and IV closing behind it and practically concealing it in a back view. With its increased size it becomes triangular in cross section and lies wedged against II and IV with a broad flat anterior face and two postero-lateral faces fitting closely to flattened antero-lateral faces in II and IV. Below this, the divergence of II and IV leaves its distal end free.

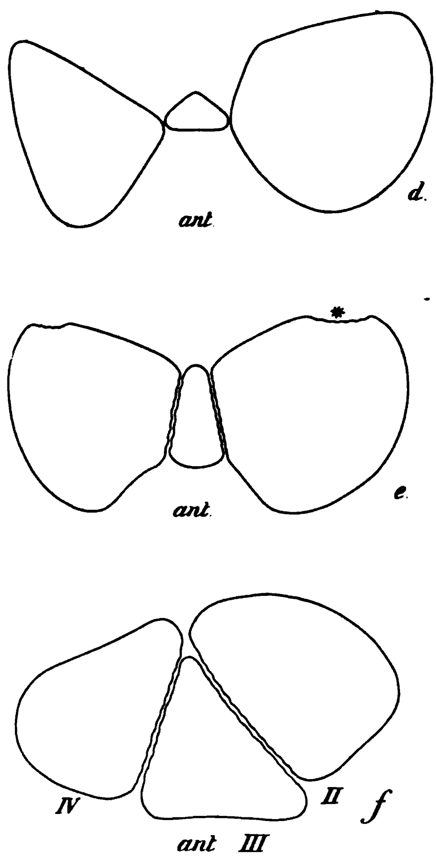


Figure 45. Outlines of transverse sections of metatarsals II, III, and IV, of the right foot of the type of Gorgosaurus; ½ natural size. *ant*, anterior; *d*, toward the proximal end; *e*, at midlength; *f*, toward the distal end. (See *d*, *e*, *f*, Figure 44); * surface of attachment of Mt. I.

Metatarsal IV is less robust throughout and slightly longer than No. II. At midlength its shaft is subquadrangular in cross section with the antero-posterior diameter greater than the transverse one. The front face is narrow and somewhat elevated toward the outer side where it curves evenly backward. The outer and back faces are flat and meet postero-externally sharply at a little less than a right angle. The inner

face, applied to metatarsal III, is flat and sharply angulated where it meets the front and back faces.

Above midlength the shaft becomes triangular in cross section being narrowly and prominently rounded in front, with a broad, flat external face, and less extensive, sub-equal, flat postero- and antero-internal faces meeting at an obtuse angle, while the postero-internal face meets the external one at an angle of about 47 degrees. Here the antero-posterior diameter is considerably greater than the transverse one, and the posterior (postero-internal) face is directed obliquely inward.

Toward the lower end the shaft is narrower as seen from the front. Transversely it is here subtriangular in outline with a rounded antero-external face directed obliquely outward. The bone extends inward to meet metatarsal II behind No. III with a broad posterior face, and an equally broad antero-internal one fitting closely against metatarsal III, the maximum transverse diameter being less than the antero-posterior one.

Metatarsal II is a heavier bone than No. IV but has very much the same shape reversed. The proximal end is larger and the shaft is thicker with the angulation of the anterior face above the midlength more broadly rounded.

The distal end of metatarsal III is larger on the inner than in the outer side, and of the two pits which occur, one in each of its concave sides, the inner one is somewhat larger and deeper than the other. The articulating surface is flat transversely and runs up in front farther than it does behind. In front there is an excavation above this surface, extending across the bone, and deepest at its mid-breadth. Posteriorly the distal end is narrower than in front, and is depressed longitudinally at the middle, leaving a slight prominence on either side on which the articulating surface encroaches.

In the distal end of metatarsals II and IV the lateral excavations occur but with the development in each of a pit only on the side next to metatarsal III. The articulating surface is convex transversely as well as fore and aft, and is continued upward in front only slightly more than it ascends behind. In contrast to metatarsal III the lower ends in Nos. II and IV are broader behind than in front. With this greater breadth there is posteriorly a more pronounced median excavation, between very prominent lateral convexities and dividing the articular surface behind.

In metatarsals II, III, and IV the front and free lateral faces of the shaft are smooth. Where these bones are in contact the surface is roughened. Distally on the posterior prominences, anteriorly above the articulating surface, and in and near the side excavations rugose, longitudinal striations are developed. The small, well-defined surface

(Figure 7) on metatarsal II for the attachment of metatarsal I is moderately rough, and on the external face of No. II proximally toward the front there is a roughened boss of considerable size, also a decided roughness occurs along the outer, angulated edge of the posterior face of No. IV near its midlength.

Metatarsal III is hollow near its distal end for a distance of about 120 mm., the space having a maximum diameter of 22 mm. In metatarsals II and IV a cavity, having about the same diameter as that of No. III, is continuous through the whole length of the shaft.

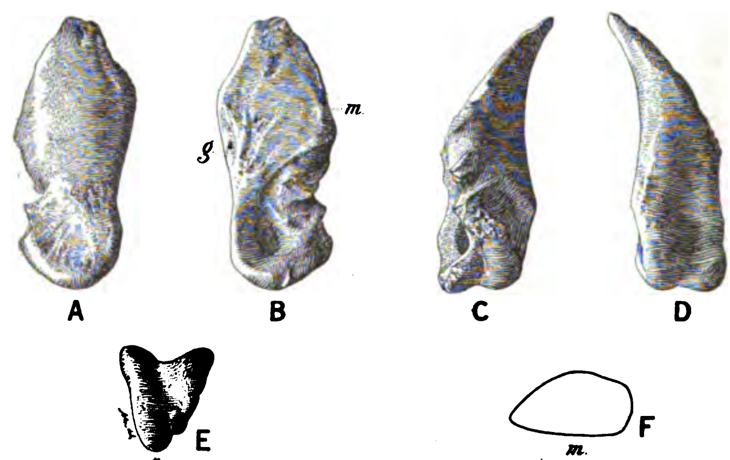


Figure 46. Metatarsal I of right foot of type of Gorgosaurus; ⅓ natural size. A, posterior aspect; B, anterior aspect; C, interior (dorsal) aspect; D, exterior (plantar) aspect; E, inferior aspect; F, outline of transverse section near midlength at *g*; *m*, surface of attachment to metatarsal II, * dorsal side.

Metatarsal I (Figure 46) is greatly reduced and is a very short but stout bone representing the distal end only of the element. In the type this vestigial bone is preserved wholly. It is in place in the right foot but has shifted slightly in the left. It is attached to the inner side of the posterior face of metatarsal II at the latter's midlength and is hidden when the metatarsus is viewed directly from the front. Its general direction is downward at an angle of about 40 degrees to the longitudinal axis of metatarsal II. In its posterior position, gained by rotation backward and outward from the inner side of No. II, its dorsal face is directed inward and the plantar face outward, the external face is turned to the front, and the internal one to the rear. In describing the bone in position, therefore, the external and internal faces will be referred to as the anterior and posterior ones respectively.

Distally the bone is broad on the plantar side, narrows to an irregullarly rugose dorsal face, and is larger on the posterior than on the anterior side. The distal articulating surface is rather small, is developed most on the posterior side, and does not extend far upward either dorsally or externally. It has a shallow median groove which passes into a broad depression in the plantar face. Above the distal articulating surface the anterior and posterior faces are excavated, very shallowly posteriorly, but deeply with the development of a large pit anteriorly.

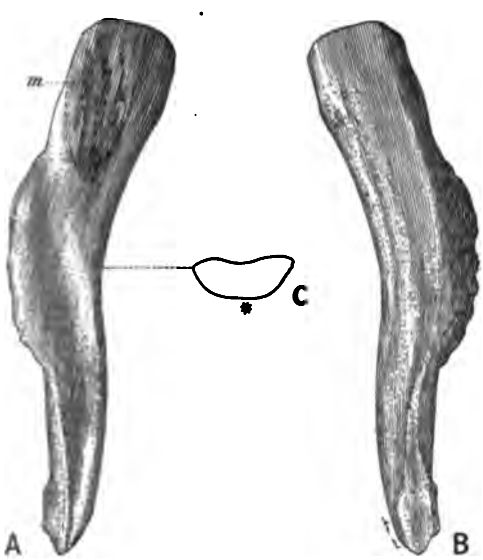


Figure 47. Metatarsal V of the left foot of the type of Gorgosaurus; $\frac{1}{3}$ natural size. A, inner view: B, outer view; C, outline of transverse section near midlength; *m*, surface of attachment to Mt. IV; * outer side.

In its upper half the bone is very obliquely truncated on its anterior side and ends above in a thin edge, the truncation providing a surface, large in proportion to the size of the bone, for contact with metatarsal II. This surface is rugose, slightly convex, and narrowly rounded in outline above. From the deep anterior pit two large, clearly defined grooves cut across the roughened dorsal face and disappear posteriorly. The surface of the bone is roughened for muscular attachment on all faces distally.

Attention was drawn in 1914 in the original description of Gorgosaurus (ante p. 7) to the presence in this carnivore of a fifth metatarsal represented by a vestigial proximal end. This bone is in place in both hind limbs of the type specimen, as well as in the left one of another individual of this species represented by a partial skeleton (Cat. No. 350) of the 1914 collection from the Belly River formation of Red Deer river. The fifth metatarsal occurs, reduced in like manner, in the Triassic *Anchisaurus colurus* Marsh, from Connecticut, in the Jurassic species *Hallopus victor* Marsh, and *Compsognathus longipes* Wagner, from Colorado and Bavaria respectively, and the Cretaceous *Ornithomimus altus* Lambe, from Alberta.

Metatarsal V is a short, laterally compressed, curved bone, representing the proximal end only of the element and recalling to mind the vestigial fifth of *Ornithomimus altus*. In the type it is preserved

in each foot and is in place at the proximal end of metatarsal IV. It is about 8½ inches long, or slightly more than ⅓ the length of No. III, and a little less than twice the length of No. 1. It narrows downward and is proximally roughly elliptical in transverse section with the greater diameter fore and aft. At the lower end it is narrower from front to back but has much the same thickness from side to side as it has above. In lateral aspect it is slightly curved with the front outline concave and the back one convex. Prominent rugosities are developed on the back border at its midlength, accentuating the curve of the bone and giving it the appearance of being abruptly bent at the middle. On the inner face proximally there is an irregularly oval roughened area, marking the surface of contact with metatarsal IV, and the lower end is rugosely striated in the direction of the bone's length.

Digit I in its pendant position at the high level has its plantar surface facing outward with an inclination to the rear due to a slight twist in its downward curve. This digit is not opposed to the other three nor has it their same general direction but it is set almost at right angles to them, certainly nearly at right angles to the forwardly directed third digit. In the original description of Gorgosaurus digit I was stated to have a "forwardly rather than a backwardly directed position in the foot." A further study, however, makes it clear that a direction rather midway between these extremes is the true one. The first digit could have been of little use in the foot on account of its shortness, its direction, and its height above the others. The tip of its ungual only reaches the level of the lower end of the second metatarsal and consequently must have been some distance above the ground when the animal walked. In the domestic turkey the claw of the first digit just touches the ground when the bird is standing, although the first metatarsal, supporting two phalanges, is applied to the co-ossified metatarsals only slightly above their lower end instead of at the mid-height of the metatarsus as in Gorgosaurus.

The second, third, and fourth metatarsals with their elongation, their very close contact, and their distal divergence, need only to be co-ossified where in juxtaposition to produce a bone remarkably similar to the tarsometatarsus of the majority of birds.

Measurements of Metatarsals of Right Limb of Type.

		Mm.
Metatarsal I, length (about 4½ inches)		116
Breadth of distal articulating surface at extremity of the bone		31
Length (vertical) of surface for contact with metatarsal II		80
Breadth of same		42
Metatarsal II, length	about	508
Breadth of distal articulating surface at its mid-height		77
Metatarsal III, length	about	594
Breadth of distal articulating surface at its mid-height		92

		Mm.
Metatarsal IV, length	about	546
Breadth of distal articulating surface at its mid-height		65
Metatarsal V, length	(8½ inches)	216
Antero-posterior breadth near upper end		41
Thickness near upper end		27
Thickness near lower end		26

Phalanges. The phalangeal formula is—2 I, 3 II, 4 III, 5 IV, agreeing with that of Allosaurus, Ornithomimus, and Theropodous dinosaurs generally so far as known. The longest digit is No. III, and as metatarsal III projects beyond metatarsals II and IV, the anterior end of this digit is considerably in advance of that of the digits (II and IV) on either side of it. Digit IV is only slightly longer than No. II, and No. I is the smallest, being much reduced and less than one-half the length of No. III.

The phalanges are robust and decrease in size toward the front; they are broader than above, are constricted in the middle, and arched longitudinally beneath. In all, with the exception of the claw shaped terminal one in each of the four digits, there is a pit in each side of the anterior end. Of digits II, III, and IV those of No. III are more nearly bilaterally symmetrical than the others which develop a greater height anteriorly and posteriorly on the side next to digit III, with the exception of the penultimate one in digits II and IV which is enlarged in front on the side away from digit III.

In phalanges 1 II, 1 III, and 1 IV the proximal surface for articulation with their respective metatarsals is shallowly concave. In the other phalanges the proximal articular surface is pronouncedly concave in a vertical direction and somewhat convex transversely, there being a tendency in the more distal and shorter phalanges to form a median vertical angulation which results in a backward extension of the upper margin and less conspicuously of the lower one also. In all the phalanges the margin of the proximal articular surface is sharp-edged throughout.

The distal articulating face in the phalanges is transversely concave and vertically convex, and fits closely into the proximal face of the phalanx in front. It extends well back on to the upper and lower surfaces of the phalanx, permitting a large amount of rotation in a vertical plane.

In phalanges 1 II, 1 III, and 1 IV (as well as in their metatarsals) the distal articular face is extended farther back on the upper than on the lower surface of the bone, conspicuously so in No. 1 of digit III. In the other phalanges of these digits the reverse is the case, the lower extension being the greater, especially in No. 2 of digit II. Judging the amount of phalangeal rotation from the extent of the articular surface, the phalanges of the second row were capable of a greater rotation upward than those farther forward in the foot. It is apparent

also that the downward rotation of all the phalanges in advance of the first row was sufficient to admit of the digits being almost closed on themselves.

The upper surface of the phalanges is excavated behind the termination of the articular face. In the lower surface of Nos. 1 of the three principal digits there is a decided rugose area bounded on either side by a roughened ridge; this occurs also in the more anterior phalanges with less relief, sometimes with an absence of the ridges. As regards the anterior lateral pits, they are equally developed on either side of the phalanges in digit III and in No. 1 of digit II, but in the other phalanges the pit on the side next to digit III is usually the larger and the deeper of the two.

In both the right and left pes all the phalanges are present in the type with the exception of the ungual of digit III in each. These are represented by the pointed distal end in the left foot and by an abnormal (diseased) claw in the right foot. As the distal articular face of the penultimate phalanx of digit II is considerably larger than that of the corresponding phalanx of digit III there appears to be no doubt that the ungual of II was larger than that of III. The ungual of digit IV was smaller, and that of digit I was the smallest.

The unguals curve evenly downward, taper to a point, and are narrower above than below, the upper and lower surfaces being respectively broadly angulated and flatly convex transversely. In cross section they are subtriangular with the height and basal breadth nearly equal. The lateral face on the side away from digit III is larger and flatter than the opposite face, giving the bone in its general forward direction a decided inclination away from digit III. The junction of the lower surface with the larger and flatter of the two lateral faces is angulated to a moderate degree; on the other side the lower surface turns more rapidly upward. On each lateral face a groove curves from the tip to near the lower surface proximally, an indistinct branch of the groove being sometimes given off, near the proximal end of the bone, with an upward and backward direction. The groove on the side next to digit III is deeper and much more pronounced than the other and in this respect is in accord with the unequal development of the lateral pits in phalanges of digits II and IV already referred to. As the phalanges of digit III were bilaterally symmetrical and had equal sized pits on either side, it is probable that the ungual of this digit was also evenly balanced and had lateral grooves of equal depth.

In digit I (or hallux) the proximal phalanx is small and slender in comparison with the corresponding ones of the other three digits. The ungual phalanx is nearly as long, but not so stout as that of digit IV. In these two phalanges the side facing to the front, or the side which

would be the nearer to digit III if digit I were directed forward instead of outward, is the one in which occurs the greater development of the lateral pit and groove, in the proximal and distal joints respectively.

In the phalanges generally the surface of the bone is usually roughened by irregular striations, having a somewhat longitudinal direction, in the neighbourhood of the lateral pits and grooves, on the side and superior faces proximally, and especially on the proximal part of the lower surface. In the midlength region generally the bone is smooth but the lower surface of the unguals is inclined to be rugose throughout. The smooth articular surfaces have their boundaries distinctly defined by a line of demarcation.

Measurements of Phalanges of Right Pes of Type.

The length of the phalanges as given below, is taken from the middle of the proximal articular surface to that of the distal one, and in the unguals in a straight line to the tip, and the breadth is that of the distal articular surface at its midheight.

			Mm.
Digit 1, length		about	194
Phalanx 1,	length		100
	breadth		33
Phalanx 2, (ungual), length			95
Digit II, length		about	400
Phalanx 1,	length		164
	breadth		69
Phalanx 2,	length		121
	breadth		50
Phalanx 3 (ungual), length			120
Digit III, length		with normal ungual about	477
Phalanx 1,	length		163
	breadth		82
Phalanx 2,	length		122
	breadth		64
Phalanx 3,	length		93
	breadth		54
Phalanx 4 (ungual, abnormal in shape), length			45
Digit IV, length			410
Phalanx 1,	length		110
	breadth		77
Phalanx 2,	length		92
	breadth		63
Phalanx 3,	length		65
	breadth		56
Phalanx 4,	length		50
	breadth		44
Phalanx 5 (ungual), length			104

Some of the bones of the type specimen show signs of having been injured, and others of having been diseased in places, in the lifetime of the animal.

The right third dorsal rib had been broken or very much bent, and the thirteenth and fourteenth ventral ribs of the right side had undoubtedly been fractured. The injury is indicated by a thickening of the bone and a roughness of the surface next to where the parts had knit. Also the fibula of the left leg is irregularly thickened near its distal end and has every appearance of having been broken.

The ungual phalanx of digit III of the right pes is abnormal in shape and appears to have been diseased; it is quite small and amorphous. The penultimate joint of the same digit has been similarly affected but to a much less extent. Both phalanges give every evidence of having been affected when the reptile was alive. Metatarsal IV of the left pes shows two roughened areas evidently the result of a diseased state of the bone (Figures 6 and 7). One of these about the midlength of the bone is protrudent, the other at the distal end is less conspicuous but more extensive.

REMARKS ON THE SUPPOSED APPEARANCE, HABITS, ETC.

One may pass from the osteology of Gorgosaurus, as revealed by the type described in the foregoing pages, to a consideration of the animal as it probably was in life. The questions naturally arise: what was this creature's appearance? On what did it feed? Was it active or otherwise in its movements? What was the nature of its surroundings? Answers to these questions must be based on conjecture to some extent but certain structural characteristics of the skeleton are prominent and lead to obvious conclusions. The teeth, for instance, are those of an animal that lived on flesh. The feet were intended for movement on land only. The peculiarly short fore limbs definitely point to the use of the long hind ones as the only means of progression. The structure of the tail and its size lead to the belief that it was rather rigid and of use principally as a support and balance. The presence of a cuirass of close set abdominal ribs indicates the habitual assumption of a prone attitude. And the horizontal expansion at the lower end of the large pubic bones was evidently developed to assist in supporting the weight of the body. From these, and other less conspicuous skeletal peculiarities, it is possible to form some idea of this dinosaur's distinctive features when alive.

Gorgosaurus was lightly built for its size and had long bird-like hind limbs on which the moderately slender, lizard-shaped body, tapering to the narrow head and into the long tail, was balanced when the creature stood or walked. The principal limb bones were hollow and empty spaces occurred in the thickest parts of the vertebræ and phalanges but not in the slender bones or parts that were flattened or attenuated. The animal walked on the strong hind limbs only, the fore ones being extremely short and relatively feeble. When seated or stretched on the ground the pubic bones received some of the weight of the body. The pointed teeth were conspicuous objects in the large mouth. The tail, forming nearly one-half of the creature's total length, was thick at the base, broadly oval in cross section, and tapered gradually to the tip. It was not very flexible and served mainly as a counterpoise to the weight in

advance of the hip and as a support. The trunk was only slightly deeper than broad, and was broadly rounded above and flattened beneath where it was strengthened by the series of abdominal ribs extending its full length. The neck was moderately short and on the throat the skin was probably loose and baggy. No trace of the skin has been found so that its characters are unknown. The full length of Gorgosaurus was about 29 feet. In the forwardly inclined position assumed in walking the top of the head was nearly 11 feet above the ground, and the back above the hips a little under 9 feet.

The tail of Gorgosaurus was that of a land animal. It was almost circular in cross section throughout its length and not laterally compressed as in that of the trachodonts which was a swimming tail—an organ of propulsion. In Gorgosaurus the chevron bones were short with a fore and aft extension in those of the distal half of the tail where its contact with the ground was most constant. The tail functioned as a balance and its inflexibility was due principally to the interlocking of the lengthened zygapophysial processes.

Was this reptile agile, alert, and quick of movement? Was it capable of capturing its prey by a sudden rush from some place of concealment, or by overtaking it after a pursuit possibly of some length? Was its victim eaten when killed? Did it engage in spirited encounters with its own kind as depicted in Knight's well known restoration of Dryptosaurus in accordance with Cope's views subsequently modified? The writer believes that Gorgosaurus was sluggish and not a quick mover, and that it fed, not on the fresh flesh of animals necessarily of its own killing but rather on carcasses found or stumbled across during its hunger impelled wanderings.

In the flat, wooded country of the west in which Gorgosaurus lived during Belly River Cretaceous times it had as contemporaries large numbers of the plant eating trachodonts frequenting the rivers and lakes. On the land were other herbivores—several kinds of horned dinosaurs and two or three species of armoured dinosaurs. It is to be presumed that Gorgosaurus fed on these when chance offered. Living at the same time were other carnivorous dinosaurs mostly of smaller size and about which, with the exception of the slender Ornithomimus, little is known. Fish abounded, as well as amphibians, crocodiles, turtles, and small mammals, and these also may have enticed the appetite of Gorgosaurus.

The fact that Gorgosaurus was a land dweller may account to some extent for the scarceness of its remains as compared with those of the trachodonts and the other plant eaters as the rule probably held then with dinosaurs as now with mammals that flesh eaters are less numerous than the herbivores on which they subsist. It may also partly account for the absence in the rock of impressions of its skin. The amphibious

trachodonts, of whose tuberculated skin impressions are commonly preserved, were entombed generally in water laid deposits and were probably rapidly covered after death before decomposition had gained much headway, whereas the bodies of the land dwelling carnivorous dinosaurs probably seldom found their way into river or lake. It is reasonable to assume that the carnivores, in common with the horned dinosaurs and armoured dinosaurs—being all land dwellers—were subjected to atmospheric conditions after death with the result that skin impressions would be less liable to occur.

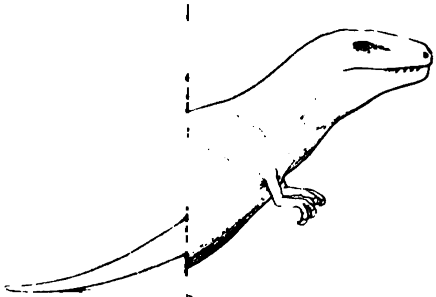
It does not follow that because skin impressions of Gorgosaurus and other carnivorous dinosaurs have not yet been found that the skin was delicate and smooth; for of the many forms of horned dinosaurs known the skin impression of one only, viz., *Chasmosaurus belli*, Lambe, has been discovered revealing the presence of an outer layer of rather small polygonal plates[1] which imply a rough and by no means thin or delicate covering. The thick bony scutes of the armoured dinosaurs are usually well and abundantly preserved though not generally in place.

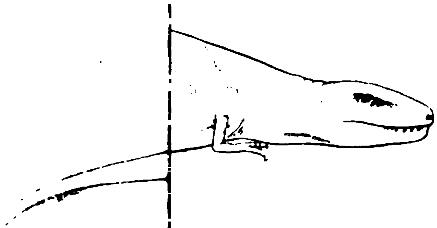
The four restoration drawings forming Figure 48 are based on the very complete type skeleton of Gorgosaurus and represent the creature standing, sitting, feeding, and lying stretched at full length. They are the work of Mr. Arthur Miles, prepared under the writer's direction.

The semi-erect position in standing or walking, given in Figure 48a, provides a perfect balance at the hip. Thus poised with the body and head stretched forward, the tail lightly touched the ground. The thighs, judging from the shape of the head of the femur and its position in the acetabulum, were inclined slightly outward. The feet were not far apart and made a double track when the animal walked. If a turn from a straight course were made it is probable that a balance was preserved by a swing of the tail. If this reptile were capable, under strong impulse, of making a rapid forward movement, the tail, functioning fully as a balance and assisting in regulating direction, would probably leave the ground. The perfect balance of the body would allow of a natural and easy movement of the head to the ground but it is not thought that a much more erect position than the one shown in Figure 48 was habitual or long sustained when standing or walking. It is believed that a reptile of the size of Gorgosaurus was not capable of jumping.

The size and shape of the pubic bones suggest the frequent assumption of a sitting or squatting position (Figure 48b). In this position

[1] On the fore limb of a carnivorous dinosaur from the Belly River formation of Alberta, and a new genus of ceratopsia from the same horizon, with remarks on the integument of some Cretaceous herbivorous dinosaurs, by Lawrence M. Lambe; Ottawa Naturalist, vol. XXVII, p. 131, p. XIV, 1914.





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the animal's weight would be borne by the pubes, the base of the tail, and the feet, the legs being well bent at the knee with the thighs directed forward and slightly outward, in fact very much in the positon in which the left limb was found when the type skeleton was discovered (Figure 6). This position of rest, and particularly the recumbent one of repose at full length (Figure 48d) were probably those most frequently assumed by a reptile having the form, and the supposed sluggish disposition of Gorgosaurus. The fore legs were probably of assistance in minor changes of position when prone, or when rising to a sitting posture, and also for receiving the weight of the fore part of the body when bringing its full length to the ground.

It is believed that Gorgosaurus did not eat while standing but that a semicrouching posture (Figure 48c) was adopted when feeding. The minute fore limbs were too short to be of any use in this connexion and the hind feet were incapable of grasping an object as the first digit was not opposed to the other three. The powerful, clawed toes may have been used to tear flesh from bones. It may be supposed that after a carcass had been sufficiently torn by the claws that the animal sank to a crouching posture for its meal.

An interesting fact in connexion with the type of Gorgosaurus is that none of the teeth shows signs of wear to any extent. The tips of the teeth where most abrasion would be expected, especially in the larger side ones, are almost perfect, the delicate denticulations of the sharp edges remaining intact to and over the pointed end. This indicates either extreme juvenility, or that the food eaten had little abrasive effect on the teeth and was obtainable with little exercise of strength. But the type of Gorgosaurus represented an individual of large size which though not aged had probably reached maturity, and it follows, therefore, that the only conclusion to be drawn from the state of the teeth is that the food was soft, non-abrasive, and obtainable without much effort. It is believed, therefore, that Gorgosaurus confined itself to feeding upon carcasses of animals that had not been freshly killed, that it was not as an intrepid hunter but as a scavenger that it played its useful part in nature, and no doubt its services were fully required when we consider the immense numbers of trachodonts, ceratopsians, stegosaurs, and other dinosaurs and reptiles that lived and died at this particular time of the Cretaceous period.

The prevalence of tree trunks and leaves in the Belly River formation of Alberta indicates that this western land was well wooded in Cretaceous times. The country was low lying, dotted with lakes, and traversed by eastwardly flowing rivers. Glades and sparsely wooded tracts no doubt interspersed the heavily timbered areas affording suitable environments for the varied and numerous reptiles both large and small. The

swamps, rivers, and inlets of the southern sea had their quota of water-frequenting and purely aquatic types. Water plants abounded. On the land were ferns and shrubs of various kinds besides a diversity of trees—pines and other conifers, cedars, poplars, oaks, birches, elms, and maples.

The type of Gorgosaurus is an example of a land dinosaur entombed in a water borne deposit. One can conceive that the body of this animal, floating with the left side uppermost, was stranded feet first in shallow water, and that the right limbs, touching bottom first, were forced upward toward the back into the position in which they were found. With the settlement of the body into the sand all the bones of the right side would be held firmly in position, accounting for the presence of all the bones of the right side in the type. In the case of the left side of the specimen the loss of a number of parts, notably the scapula, fore limb, and the left half of the cuirass of ventral ribs, could result from the body lying with that side uppermost in shallow water, possibly more or less exposed to the air, for a considerable interval of time subject to the action of water or the depredations of animals or both.

It was in a land of the above character that Gorgosaurus played its part in the economy of nature, and although many of this reptile's habits and characteristics are at present only surmised, others are clearly indicated by its fossil remains.

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W. D. Matthew

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No. 5

The Hadrosaur Edmontosaurus from the Upper Cretaceous of Alberta

BY

Lawrence M. Lambe

OTTAWA
THOMAS MULVEY
PRINTER TO THE KING'S MOST EXCELLENT MAJESTY
1920

No. 1824

CONTENTS.

Illustrations.

The Hadrosaur Edmontosaurus from the Upper Cretaceous of Alberta.

INTRODUCTION.

The Hadrosauridæ[1] are a group of herbivorous dinosaurs of which most of the genera are from the continent of North America. The literature relative to this family is both voluminous and involved. The earlier descriptions were based often on inadequate material which gave little information as to the relations of the forms represented and their variety which has proved to be much greater than was at first supposed. The rapidity of the evolutionary changes that took place in these reptiles during Cretaceous times, especially toward the close of the period, resulting in a wonderful diversity of form, could not, in the circumstances, be fully appreciated. At the early stage of geological and palæontological investigation the horizons supplying dinosaurian remains had been only broadly determined. Geological exploration was at that time carried on, in the west particularly, under trying and arduous conditions; transportation was difficult; and rough-and-ready methods of collecting were used by parties most inadequately equipped for field work according to present day standards. It is not surprising, therefore, in spite of the brilliancy of the pioneer few who undertook palæontological investigation, and the ardour which they brought to bear on their work and by which they were upheld, that errors were not avoided. It does not detract from the excellence of their results to now find that diversity of form was not always recognized, that, for instance, generic terms were employed to include types not only widely separated by time intervals but also by very decided differences in structure.

Recent discoveries during the last six years in the Belly River and Edmonton formations on Red Deer river, Alberta, of nearly complete skeletons of several distinct types of hadrosaurs have provided excellent material for study and description, thrown much light on the osteology of the group, and opened the way for a classification of its members.

In the following pages a description of the large hadrosaur *Edmontosaurus regalis,* Lambe[2] from the Edmonton formation of Red Deer river, Alberta, is followed by a proposed division of the Hadrosauridæ into three subfamilies the classification being based principally on type and other material resulting from the exploratory work of vertebrate palæontological field parties of the Geological Survey, Canada, in Alberta, largely supplemented by the discoveries of the American Museum of Natural History, New York, in the same region and to the south of the International Boundary.

Of the two skeletons on which the genus *Edmontosaurus* was established in 1917, one is unique in that the majority of the bones of the head and of the remainder of the skeleton were found together naturally dis-

[1]The name Hadrosauridæ proposed by Cope in 1869 (1871) has precedence over Trachodontidæ used by Lydekker in 1888 and later by Marsh in 1890.

[2]A new genus and species of crestless hadrosaur from the Edmonton formation of Alberta; Ottawa Naturalist, vol. XXI, No. 7, Oct. 1917, pp. 65–73, pls. II and III.

articulated, well preserved with remarkably little distortion, in a soft clayey sandstone easily removed and leaving the surface of the bones clean. This particular state of preservation provided an opportunity for study and description seldom accorded. A preservation of this nature was especially welcome in the skull as in the generality of cases the elements of the skull in dinosaurs are found in place and are not easily freed from each other. Any particular bone is largely hidden by the surrounding ones, and it is a matter of difficulty, often of impossibility, to remove it in order to see it in all its aspects. Also, when a skull is preserved with the elements in place any distortion that may have occurred is likely to affect all of the elements to a greater or less extent. In a naturally disarticulated skull, distortion when present in any particular bone is confined to the limits of that bone. With few exceptions all the drawings reproduced in this memoir in illustration of the text were made by Mr. Arthur Miles under the supervision of the writer.

MATERIAL ON WHICH EDMONTOSAURUS IS BASED.

Edmontosaurus is represented in the collections of the Geological Survey by remains, including the skull, of at least two individuals, as follows:

Collection of 1912, Edmonton formation, Red Deer river, Alberta, field No. 27, Cat. No. 2288, genotype, from opposite the mouth of Three Hills creek, at 200 feet above the level of the river: the skull figured and described in this paper, with most of the vertebræ in place back to the sixth caudal, one hind limb lacking a few phalanges, one humerus, both pubic bones together, one ischium, the greater part of the right ilium, and some ribs. Estimated length of individual considerably over 30 feet. From field measurements the length of the following bones are: femur 47 inches, humerus 27 inches, ischium 54 inches. The discovery of this specimen was made by L. Sternberg, assistant on the Geological Survey party of 1912.

Collection of 1916, Edmonton formation, Red Deer river, field No. 6, Cat. No. 2289, paratype, found by G. F. Sternberg 7 miles west and north of Morrin, in sec. 16, tp. 31, range 21, on the west side of the river, 90 feet above water level: a skeleton lacking some of the bones of the feet, the tail vertebræ behind the fifth caudal, the premaxillaries and the predentary. There is a possibility of the right ilium not being present. The bones of this individual are splendidly preserved and lay closely scattered within a grey, clayey sandstone which is easily removed leaving the surfaces in good condition. The elements composing the top of the skull are preserved together. The remaining bones of the head, including the mandibles, were found disarticulated. Femur 49 inches long, humerus 27½ inches, left ulna 30 inches, left radius 26 inches, largest right rib 50 inches along the curve, dentary 30 inches, depth of dentary in advance of base of coronoid process, from the lower surface to external alveolar border 6¼ inches.

Of the type skeleton the skull only (Figures 3 and 4) has as yet been prepared. This work was skilfully performed by L. and C. M. Sternberg.

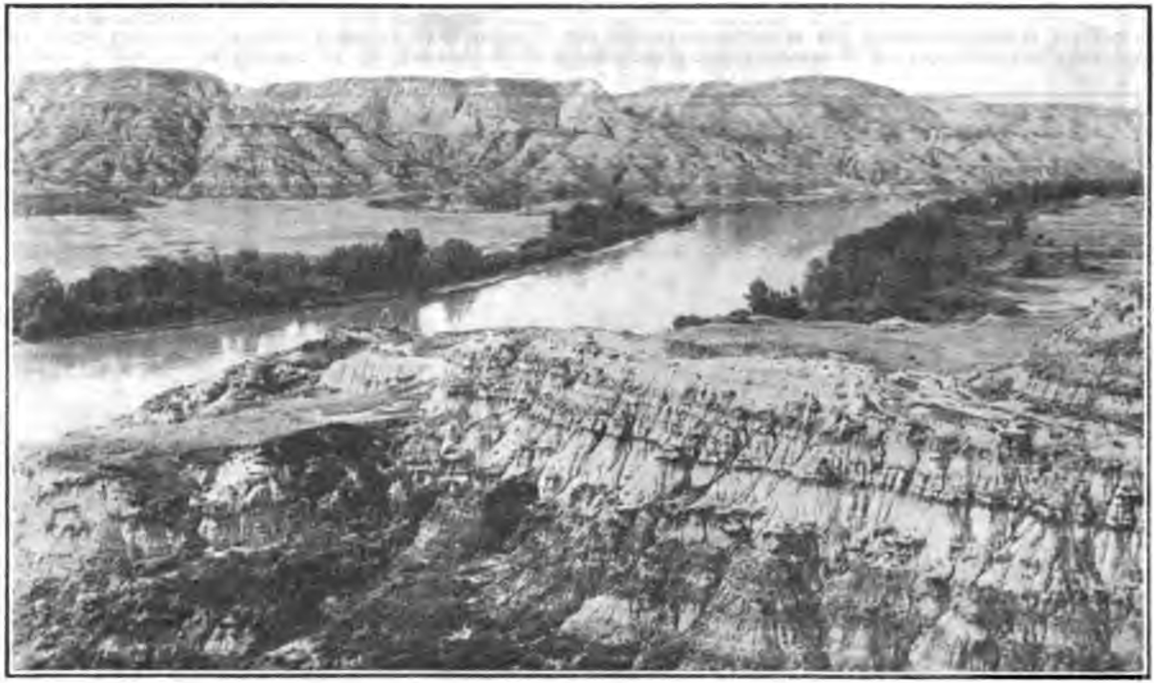

Figure 1. A typical view on Red Deer River, Alberta, showing the sandstones and clays of the Edmonton formation a few miles above where the 1916 specimen of Edmontosaurus was found. The beds of this formation flank the river on either side for a distance of about 100 miles. At this point the valley is 400 feet deep.

Figure 2. Site of the discovery of the 1916 specimen of *Edmontosaurus regalis* in rocks of the Edmonton formation in the valley of Red Deer river, Alberta, 7 miles west of Morrin. The banded character of the Edmonton beds is brought out well by the photograph.

The elements of the skull of the paratype, and the few vertebræ and bones of the fore limb mentioned in this report, were prepared by G. F. Sternberg who had charge of the 1916 expedition. It is hoped soon to assemble the elements of this skull and to so mount them that as many as possible will be removable for study purposes.

As the greater part of the skeleton is present in the above specimens an open mount of both is contemplated.

OSTEOLOGY OF EDMONTOSAURUS.

SKULL.

The skull of *Edmontosaurus* is large, massive, and long, high behind and low in front. Posteriorly it is higher than broad, anteriorly it is greatly expanded horizontally outward into a beak-like termination.

Viewed from the side its outline is subtriangular, high behind, approximately straight horizontally below, flat above behind the orbits, with a long facial slope descending rapidly forward.

As seen from above the skull is broadest in its posterior half-length, much expanded in front, and greatly constricted behind this expansion. The outline of the occiput is squarely transverse, and the margin of the snout has a semicircular curve. Behind the concavity of the anterior constriction the lateral outline is broadly convex backward.

The posterior height of the skull is greater than half its length. The maximum breadth behind exceeds the full lateral expansion of the beak, but is considerably less than the half-length. The orbit is large, as is also the narial opening. The supratemporal fossæ are of fair size, but the lateral temporal ones though high are greatly reduced in width. Concomitant with the posterior height of the skull is a long quadrate. The great development of the flattened snout is remarkable, and the depth and robustness of the mandible are equally striking.

Elements of the Skull Known in Edmontosaurus.

Alisphenoid	*Als.*	Parasphenoid	*Pasp.*
Angular	*An.*	Parietal	*P.*
Articular (in part)	*Ar.*	Postfrontal	*Pof.*
Basi-occipital	*Boc.*	Predentary	*Pd.*
Basisphenoid	*Bs.*	Prefrontal	*Prf.*
Dentary	*Dn.*	Premaxillary	*Pmx.*
Ectopterygoid (Transpalatine)	*Ept.*	Presphenoid	*Psp.*
Exoccipital	*Exo.*	Proötic	*Prot.*
Frontal	*F.*	Pterygoid	*Pt.*
Jugal	*J.*	Quadrate	*Q.*
Lachrymal	*L.*	Quadrato-jugal	*Qj.*
Maxillary	*Mx.*	Splenial	*Sp.*
Nasal	*N.*	Squamosal	*Sq.*
Opisthotic	*Opot.*	Supra-occipital	*Soc.*
Orbitosphenoid	*Orsp.*	Surangular	*Sa.*
Palatine	*Pal.*	Vomer (in part)	*V.*

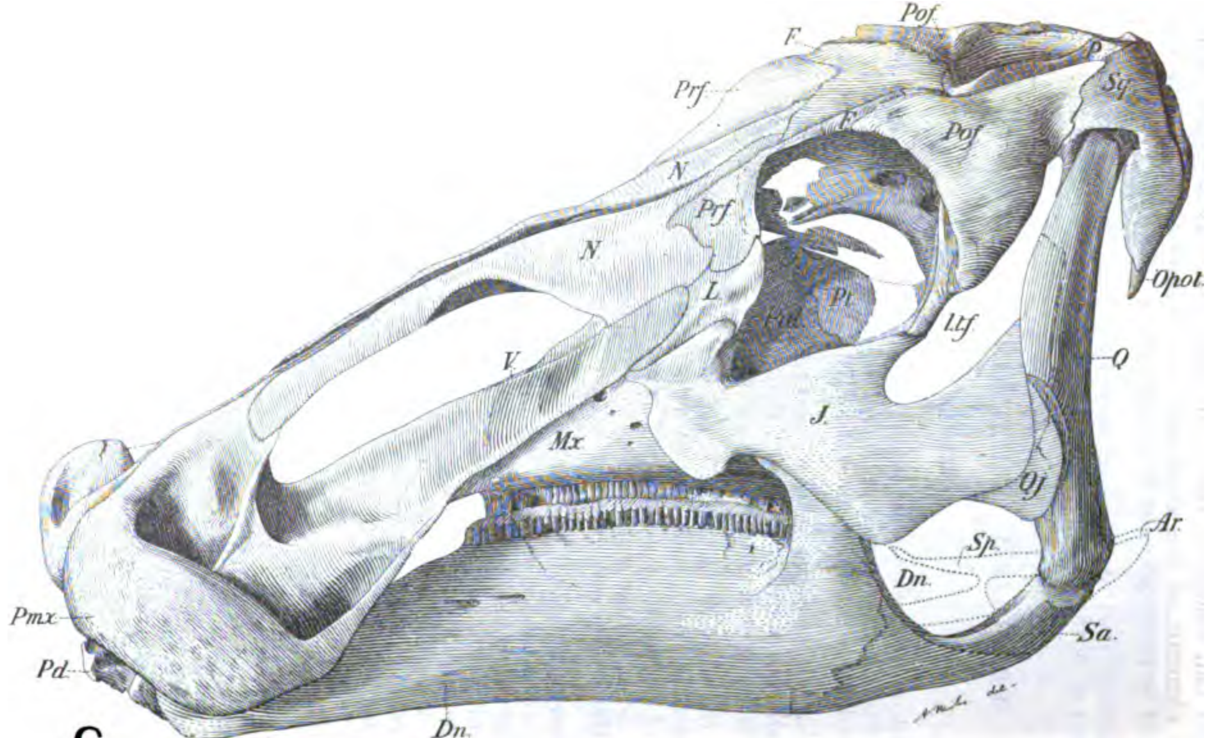

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Figure 3. Skull of type of Edmontosaurus, Cat. No. 2288; left lateral aspect; ¼ natural size. *Als*, alisphenoid; *Ar*, articular; *Dn*, dentary; *F*, frontal; *J*, jugal; *L*, lachrymal; *ltf*, lateral temporal fenestra; *Mx*, maxillary; *N*, nasal; *no*, nasal opening; *Opot*, opisthotic (paroccipital process); *Orb*, orbit; *P*, parietal; *Pal*, palatine; *Pmx*, premaxillary; *Pof*, postfrontal; *Prd*, predentary; *Prf*, prefrontal; *Prot*, proötic; *Pt*, pterygoid; *Q*, quadrate; *Qj*, quadrato-jugal; *Sa*, surangular; *Soc*, supra-occipital; *Sp*, splenial; *Sq*, squamosal; *stf*, supratemporal fenestra; *V*, vomer. II, III IV, exits of cranial nerves.

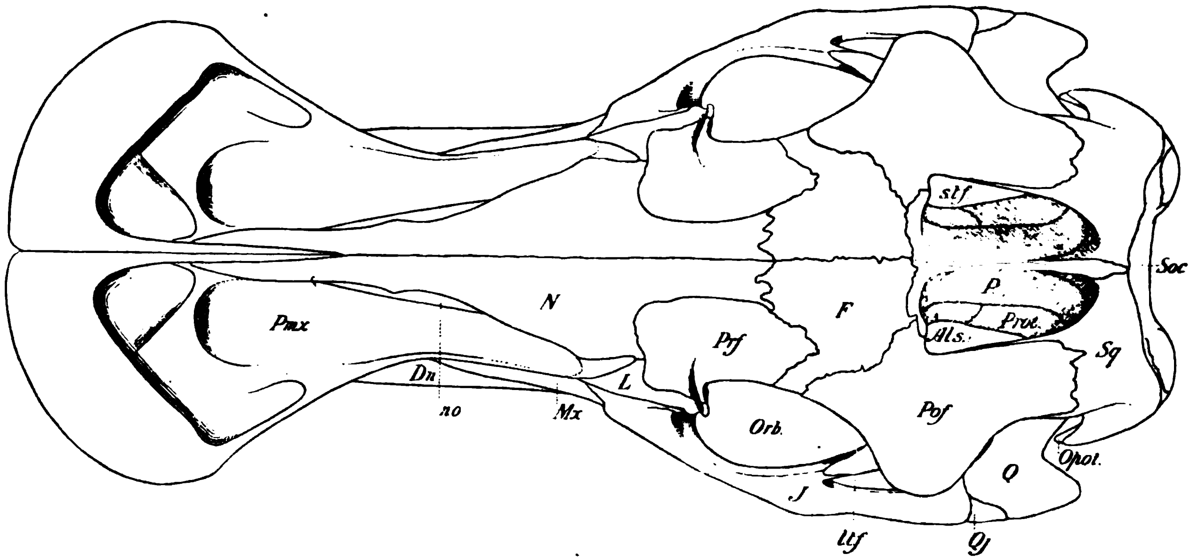


Figure 4. Skull of Edmontosaurus; superior aspect; ¼ natural size. For lettering see Figure 3. This view is taken from above with the skull in the position in which it is shown in Figure 3, viz., with the line of the teeth practically horizontal.

Cranium. The cranium proper or brain-case of *Edmontosaurus* though small in proportion to the size of the head was strongly put together. The bones entering into its formation were thick and between many of them coössification took place; at least in the paratype, on which the present description is principally based, the brain-case, although excellently preserved with wonderful detail of structure and form, exhibits few of the sutures externally in the side walls and basicranial axis. In the brain-cavity none of the sutures have been detected.

In *Edmontosaurus*, and apparently in the Hadrosauridæ generally, ossification took place throughout the cranium, in fact the brain-case in the Hadrosauridæ appears to have been as complete as in the Ceratopsidæ, and in both groups an early closing of the sutures marked a departure from conditions in the typical reptilian skull in which the cranial elements tend to remain distinct throughout life.

In the paratype of *Edmontosaurus*, in the external surface of the sidewalls of the cranium, the suture between the alisphenoid and the proötic is preserved above the foramen ovale. In a large surface extending forward from the alisphenoid, representing the orbitosphenoid and the presphenoid no sutures are seen marking the separation of these bones from each other, although their upper boundaries are very distinctly and clearly defined, and in the case of the orbitosphenoid and the presphenoid their lower limits also.

Inferiorly the suture between the basi-occipital and the basisphenoid is visible on either side, but not near the midline, and it can be traced upward on the side walls for a short distance before trace of it is lost. Also in the occipital condyle the division between the basi-occipital and the exoccipital is clear and distinct not only beneath but externally and posteriorly as well.

An early and perfect union of the opisthotic with the exoccipital, and of the epiotic with the supraoccipital would be expected, but in the side walls behind the foramen ovale no sutures can be detected suggesting a division between any of the periotic bones. Nor is there a suggestion of the extent of the supraoccipital bone.

The cranial foramina are well preserved and, relying on them, with, the aid of the few sutures that are visible, the proportionate size and relation to each other of the elements entering into the formation of the brain-case are fairly well established.

Measurements of Skull of Type of Edmontosaurus.

	Mm.
Length of skull measured in a straight line from the posterior edge of the exoccipital process (paroccipital) to the centre of the anterior premaxillary margin	1114
Horizontal length from anterior premaxillary margin to a point vertically below the preoccipital edge	1066
Height from level of posterior end of nasal at the midline of skull to lower surface of dentary	541
Height of orbit measured vertically down from centre of frontal contribution to orbital rim	205
Width of orbit at midheight	180
Length of supratemporal fossa	153
Maximum width of same near its anterior end	85
Width of infratemporal fossa toward its lower end	60
Length of quadrate	420
Breadth (antero-posterior) of external face of same at midheight	76

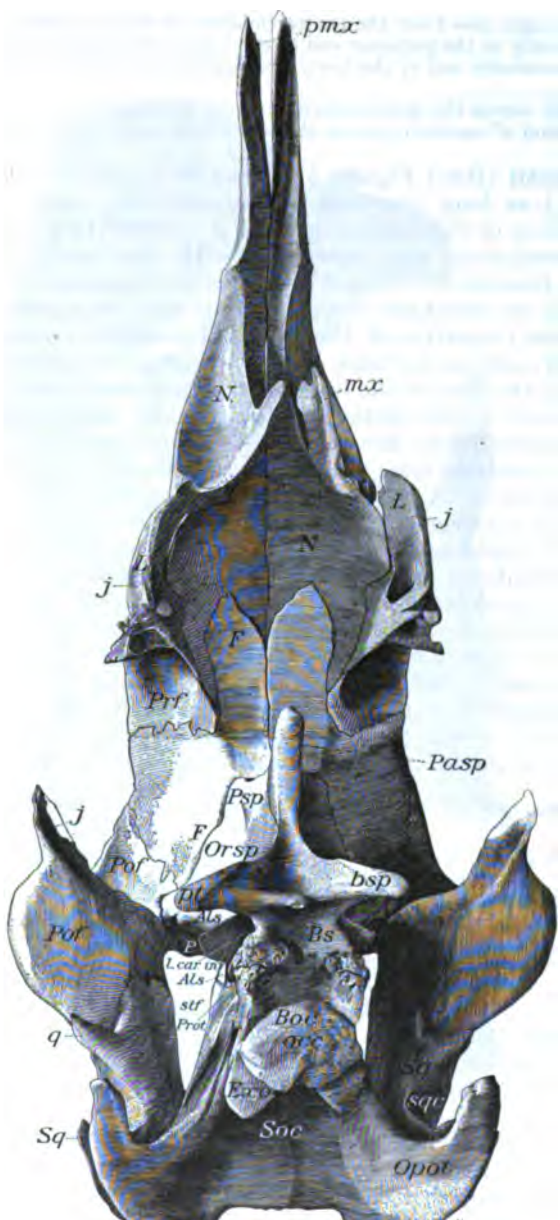


Figure 5. Cranium of Edmontosaurus, Cat. No. 2289; ⅓ natural size; inferior aspect. *Als*, alisphenoid; *Bs*, basisphenoid; *Boc*, basi-occipital; *bsp*, process of basisphenoid; *Exo*, exoccipital; *F*, frontal; *j*, surface for jugal; *L*, lachrymal; *l. car. in*, lower entrance of internal carotid artery; *mx*, surface for maxillary; *N*, nasal; *occ*, occipital condyle; *Opot*, opisthotic (paroccipital process); *Orsp*, orbitosphenoid; *P*, parietal; *Pasp*, parasphenoid; *pmx*, surface for upper limb of premaxillary; *Pof*, postfrontal; *Prf*, prefrontal; *Prot*, proötic; *Psp*, presphenoid; *pt*, surface for pterygoid; *q*, surface for quadrate; *Sq*, squamosal; *sqc*, squamosal cotylus; *Soc*, supra-occipital; *stf*, supra-temporal fenestra.

Distance in a straight line from the centre (midline of skull) of the premaxillary border anteriorly to the posterior end of the upper premaxillary limb	380
Distance of the posterior end of the lower premaxillary limb from the same point anteriorly	635
Maximum breadth across the premaxillaries in front (estimated)	460
Height of upper end of coronoid process above lower surface of dentary	288

Basi-occipital (*Boc.*) *Figures 5, 6, and 26.* This is a robust, compact bone as broad as long but with a comparatively slight depth. As the posterior member of the basicranial axis it is in contact supero-posteriorly with the exoccipitals, and anteriorly with the basisphenoid. Supero-anteriorly its boundaries are not seen but it comes in contact here with the proötic and no doubt also to some extent with the opisthotic. It enters largely into the formation of the occipital condyle, bounds the foramen magnum below, and, in advance of this opening its upper surface forms a large portion of the floor of the brain-cavity beneath the medulla oblongata. It supplies about five-sevenths of the articular surface of the occipital condyle, the exoccipitals between them providing the remaining two-sevenths. Its contribution to the condyle includes more than one-half of its lower surface. Viewing the bone from below, it is narrowest in advance of the condyle, broadening again to its contact with the basisphenoid where its breadth equals that of the condylar part. In front of the broad convexity of the condyle the lower surface of the bone is transversely concave, and on either side anteriorly a rugose but not particularly prominent tubercle is developed whose roughness and tumidity is continued on to the basisphenoid. The contact of the basi-occipital and the basisphenoid is seen in the paratype toward either side of the lower surface, and can be traced upward externally for a short distance. Posteriorly the basi-occipital extends back for some distance beyond a point vertically below the roof of the foramen magnum.

Measurements of Basi-occipital of Edmontosaurus, Specimen Cat. No. 2289.

	Mm.
Breadth inferiorly in posterior half (across condyle)	98
Breadth inferiorly at junction with basisphenoid, about	102
Length, inferiorly, about	100
Thickness (depth) at centre of basisphenoid contribution to occipital condyle, about	30
Thickness (depth) at midline in front, about	36

Exoccipital (*Exo.*) *and Opisthotic* (*Opot.*). *Figures 5, 6, 7, and 26.* The exoccipitals, the lateral elements of the occipital segment of the cranium, form the side walls of the brain-cavity in its most posterior part, bound the foramen magnum on either side, and contribute largely to the occipital condyle. They are closely united, without trace of suture, to the opisthotics with which bones they evidently effected an early and thorough fusion. In their completion of the occipital condyle externo-posteriorly they project freely backward and are convex inferiorly and externally; they are angulated behind, and shallowly concave internally where they form upward and backward extensions of the floor of the foramen magnum.

In the occiput the exoccipitals are thought to have been separated partly, if not wholly, by the supraoccipital, but in the absence of sutures defining the limits of the latter bone nothing definite can be said in this

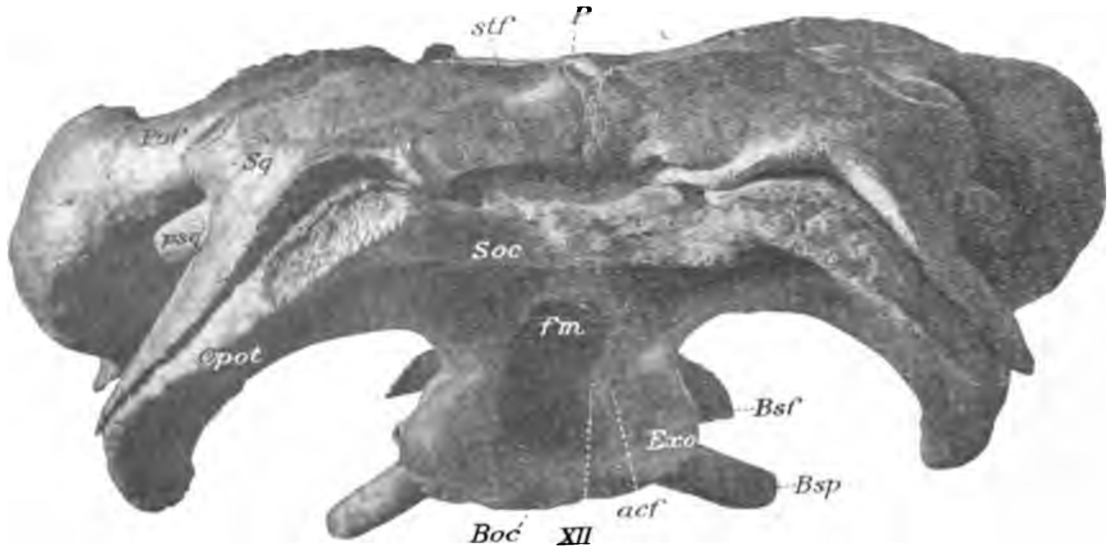


Figure 6. Posterior view of cranium of Edmontosaurus, Cat. No. 2289; ½ natural size. *Boc*, basi-occipital; *Bsf*, flange of basisphenoid; *Bsp*, process of basisphenoid; *Exo*, exoccipital; *fm*, foramen magnum; *Opot*, opisthotic; *P*, parietal; *Pof*, postfrontal; *Psq*, process of squamosal; *Soc*, supra-occipital; *Sq*, squamosal; *Stf*, supratemporal fossa; XII, foramen for twelfth nerve; *acf*, anterior condylid foramen.

connexion. In *Camptosaurus* the supra-occipital bounded the foramen magnum above and in *Edmontosaurus* it is probable that it occupied the same position.

The opisthotic portion of the exoccipital-opisthotic complex extends backward, with a slight inclination upward from the horizontal, and develops posteriorly a large forwardly hooked paroccipital process directed outward and downward beneath the squamosal process which it supports and resembles somewhat in general shape, and beyond which its pointed end projects.

Above the lateral convexity of the occipital condyle is a concave surface in which are four foramina (Figures 26 and 27, *IX*, *X*, *XI*, *jug. v*, *a. c. f.*, *XII*) to be referred to later, piercing the exoccipital. A strong, backwardly directed ridge, springing from the basi-occipital, bounds the convexity above and merges farther back into the lower marginal curve of the paroccipital process. Above the ridge the external surface is widely channelled longitudinally behind the fenestra ovalis (Figure 26, *fen. ov.*), and it is in this upper depression that the division between the opisthotic and the epiotic would be expected. In this channel was probably lodged the stapes whose anterior end closed the fenestra ovalis.

Supra-occipital (*Soc.*). *Figures, 4, 5, and 6.* Extending back from the transversely angulated upper rim of the foramen magnum is an extensive flat surface of bone which lies between the paroccipital processes of the exoccipital and broadens backward with an inclination upward from the horizontal. No indications of sutures are found in this region and evidently the supra-occipital which would be expected here in the midline, and the exoccipitals have completely coössified. It is impossible, therefore, to determine definitely the limits of the supra-occipital, but it is thought probable that the greater part if not all of this surface is supplied by the supra-occipital and that this bone entered into the formation of the foramen magnum above, confining the exoccipitals to the flanks of the opening somewhat as in *Diclonius mirabilis* as figured by Cope (1883, pl. VII).

A definite ridge extends backward from the foramen magnum along the midline of this supposed supra-occipital surface, and anteriorly on either side of the ridge the bone is widely excavated upward behind the foramen magnum, the exoccipitals flanking the excavations externally.

The back border of this surface is straight transversely for some distance outward from the midline and then suddenly acquires a greater backward protrusion which curves evenly outward into the paroccipital process. On the upper face of the protruded border on each side are curved impressed lines (Figure 8, *c*) which may indicate the postero-external limit of the supra-occipital.

The anterior contact of the supra-occipital with the parietal is not seen, but posteriorly there is a space between these two bones, a low space which extends outward for a short distance, about 20 mm., from the midline beneath the squamosals.

Viewing the skull from below, its extension backward from the foramen magnum is conspicuous. A noteworthy feature, in a posterior aspect, is the lowness of the parieto-squamosal arch in comparison with its breadth, as well as the smallness of the parietal contribution to the arch. Beneath this arch, following its curve, and closely applied to it, except near the

midline, is the supra-occipito-paroccipital arch. Between the parietal and inner part of the squamosals and the hinder border of the supra-occipital, the space, representing apparently a confluence of the posttemporal fenestræ occasioned by the very limited entry of the parietal into the occiput, extends forward for at least 50 mm., beyond which it has not been possible to follow it. Issuing from either side of the space is a well-defined groove (Figure 6, *d*) in the squamosal which ascends outward to the upper surface of the bone and there disappears. Between the squamosal and the supra-occipital, and below the groove is what appears to be a foraminal opening (Figure 6, *e*).

Basisphenoid (*Bs.*). *Figures 5, 6, 7, and 26.* This element, preceding the basi-occipital in the basicranial axis, and constituting the inferior member of the parietal segment of the cranium, is a robust bone of distinctive shape. It is in contact behind with the basi-occipital, above with the alisphenoids and orbitosphenoids, and presumably supero-posteriorly with the proötics also, but except in front where it runs beneath the orbitosphenoids its upper boundaries cannot be made out in the material available. Anteriorly it extends forward, without trace of suture, as the parasphenoid.

In inferior aspect this bone is broad posteriorly, contracts forward, and then throws off to either side, from slightly in advance of what is considered to be its midlength, a stout process which is directed outward and slightly downward to connect with the upper border of the pterygoid between that bone's alar extensions. In front of the processes the bone narrows rapidly to the breadth of the slender parasphenoid. The outline of the bone, as seen from below, may be said to be irregularly star-shaped with five rays composed of the anterior constriction, the lateral pterygoid processes, and the postero-lateral angles, the rays represented by the processes being longer than the others.

The lower surface of the basisphenoid is crossed at about its midlength by a strong transverse ridge connecting the two processes infero-posteriorly. Behind this ridge the lower surface of the bone lies in the general plane of the basi-occipital, is transversely concave, and postero-laterally is rugosely tumid next to and supplementing the basi-occipital tubercles. The posterior slope of the transverse ridge faces backward and very slightly downward. In advance of the ridge the surface of the bone between the processes is widely concave in all directions, and is inclined strongly upward so as to face obliquely forward and downward, much as in *Iguanodon*. Medially on the ridge a small, tongue-shaped process is developed which points downward with a slight backward curve.

The pterygoid processes are flattened above and below, are thickest behind, and narrow to the front, the cross-section at the base being triangular with the apex of the triangle directed forward, and the sides lengthened. They terminate bluntly. Covering their thick, obtuse ends and extending inward with decreasing breadth for a distance of over 60 mm., on their front faces is a roughened surface denoting contact with the pterygoid. Between this articular surface and the parasphenoid the bone comes to a sharp edge.

Supero-laterally, above its contraction behind the processes for the pterygoid, it sends outward a thin, triangular, wedge-shaped flange, set at an angle to the horizontal so that its upper face is inclined forward.

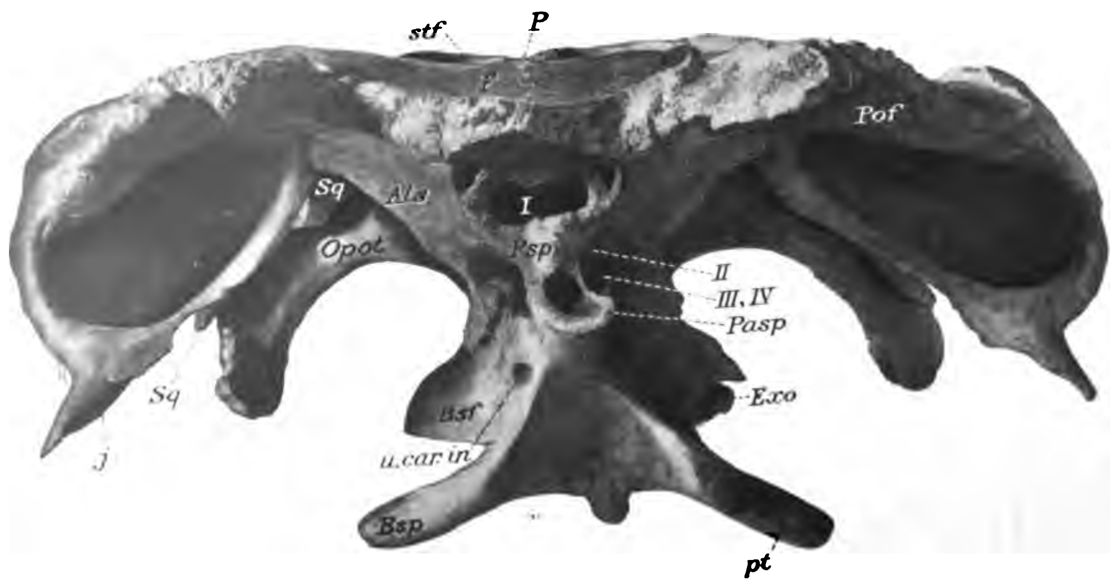


Figure 7. Anterior view of cranium of Edmontosaurus, Cat. No. 2289; ½ natural size. *Als*, alisphenoid; *Bsf*, flange of basisphenoid; *Bsp*, process of basisphenoid; *Exo*, exoccipital; *F*, frontal; *j*, surface for jugal; *Opot*, opisthotic (paroccipital process); *P*, parietal; *Pasp*, parasphenoid; *Pof*, postfrontal; *Psp*, presphenoid; *pt*, surface for pterygoid; *Sq*, squamosal; *stf*, supratemporal fossa: *u. car. in.*, upper (anterior) foramen for internal carotid artery; I, II, III, IV, exits of cranial nerves.

This flange springs from a stout base extending from the pterygoid processes to below the foramen ovale. The outline of the base of the flange is lenticular in cross-section, with the length of the lens nearly equal to five times its breadth.

Placed well forward beneath the base of the flange is the external opening of a long, straight passage, directed upward, forward, and inward, and entering the pituitary space from below, for the transmission of the internal carotid artery. Above the flange, about midway between the anterior end of its base and the common exit for the third and fourth nerves, is a foramen for a branch of the carotid artery opening directly into the main passage. This upper opening is small and occurs within a concavity of considerable size (about 15 mm. in diameter) in the external surface of the bone. Skirting the base of the flange infero-posteriorly is a well-defined groove for the course of the artery to its entry beneath the flange.

The upper surface of the basisphenoid posteriorly forms the anterior portion of the floor of the medulla oblongata. It is here perforated by the forwardly directed passages of the sixth nerves which enter the infundibulum, one on either side of the midline, from behind. Extending down into the great thickness of the bone, in continuation of the infundibulum, is the space for the pituitary body about in line with the hinder slope of the transverse ridge connecting the pterygoid processes inferiorly.

Measurements of Basisphenoid of Edmontosaurus, Specimen Cat. No. 2289.

	Mm.
Infero-posterior breadth	110
Inferior breadth behind pterygoid processes	63
Breadth across pterygoid processes	186
Infero-anterior breadth	20
Thickness (depth) at midline, between origin of sixth nerves and infundibulum, to lower surface behind transverse ridge	66
Thickness (depth) from lower end of pituitary space to lower surface behind transverse ridge	37
Superior breadth below optic foramen	18

Parasphenoid (*Pasp.*). *Figures 3, 5, 7, and 26.* In *Edmontosaurus* this membrane bone is beneath the presphenoid as a forward extension from the basisphenoid with which it was evidently coalesced. It is slender, higher than broad posteriorly, and is spout-shaped in advance of the line of the olfactory nerve exit. Leading back from the spout, toward the basisphenoid, is a passage about 18 mm. high and 8 mm. wide, mostly through the parasphenoid but within the presphenoid to about one-third of its height. Whether this passage reaches the basisphenoid has not been ascertained. The suture between the parasphenoid and the presphenoid is indicated externally on both sides by a line of demarcation running forward below the level of, and nearly parallel with, the floor of the olfactory lobes.

Alisphenoid (*Als.*). *Figures 4, 5, 7, 8, and 26.* The alisphenoid is, in its characteristic position in the reptilian skull, in advance of the proötic, bounding the large foramen for the trigeminal nerve in front. It forms the sidewall of the brain-cavity above the hinder portion of the basisphenoid. It connects postero-superiorly with the parietal, superiorly with the frontal, and externo-superiorly with the postfrontal. Inferiorly,

fusion with the basisphenoid probably took place as the suture here is not seen, also its anterior boundary is not distinguishable and its coalescence with the orbitosphenoid in front may, therefore, have been complete.

The division between the alisphenoid and the proötic is marked by a suture which descends from the floor of the supratemporal fossa and enters the foramen for the trigeminal nerve from behind in the upper curve of that opening. The parieto-alisphenoid suture runs forward, from the upper end of the proötic suture, with a slight inclination upward, and curving outward reaches the postfrontal in advance of and below the anterior border of the supratemporal fossa.

In advance of and above the foramen ovale a stout ridge is developed which running upward and outward forms an inferior angulation of the bone between the supratemporal fossa and the orbital cavity. This ridge in its upper part constitutes a buttress which reaches the postfrontal at the upper, inner margin of the opening of the spacious postfrontal pocket. The inner portion of this upper prolongation of the alisphenoid meets the frontal from below entering into the formation of the sidewall of the brain-cavity at the posterior part of the cerebrum. In advance of the lower end of the angulation of the alisphenoid the cranium is suddenly much compressed laterally and in the hinder part of the depression of the external surface thus formed which continues upward the anterior lateral compression of the basisphenoid above the pterygoid processes, is the foramen for the transmission of the third and fourth nerves about 25 mm. in front of the foramen ovale.

The foramen ovale deeply notches the hinder border of the alisphenoid. The outer opening of this foramen is contracted in front, and from it a narrow groove extends forward on the external surface of the bone for the accommodation of the ophthalmic branch of the fifth nerve. This is much the same as in *Iguanodon* (Hulke, 1871, p. 203, pl. XI, and Andrews, 1897, p. 588, text fig.). The groove is present in a fragmentary cranium of "*Trachodon*" sp., from the Edmonton formation of Alberta, described and figured by Brown in 1914 (p. 547, pls. XXXVI and XXXVII). In *Triceratops* this branch of the nerve passed forward deeply embedded in bone and found exit at some distance in advance of the common opening for the maxillary and mandibular branches.

Orbitosphenoid (*Orsp.*) and *Presphenoid* (*Psp.*). *Figures 5, 7, and 26.* As already stated the anterior limit of the alisphenoid has not been determined, but extending forward from this element is an extensive surface between the basisphenoid and the parasphenoid below, and the frontal above. The hinder part of this surface is apparently the orbitosphenoid, and the forward part the presphenoid, but no sutures can be detected defining their boundaries except above and below where well-marked sutural lines are preserved.

In cranial material at present thought to be referable to *Stephanosaurus* the suture between the alisphenoid and the orbitosphenoid is clearly indicated extending from the foramina for the third and fourth nerves (in *Edmontosaurus* a single opening) upward, in advance of the buttress of the alisphenoid, to the frontal. Hay has found that in *Triceratops* the foramen for the third nerve and possibly the fourth lies in the boundary between the orbitosphenoid and the alisphenoid bones (Hay, 1909, p. 102). It is probable that in *Edmontosaurus* also the course of the boundary of

the alisphenoid lay from this particular nerve opening up in front of its angulated buttress. The area in advance of the alisphenoid, regarded as the orbitosphenoid, connects superiorly with the frontal and inferiorly with the basisphenoid. The presphenoid in front forms the floor beneath the olfactory lobes and may include that part of the area from the opening for the optic nerve to that for the first or olfactory nerves, and upward to the frontal, but the proportionate extent of the contact of the presphenoid and orbitosphenoid with the frontal is not known. Apparently the inferior connexion of the presphenoid with the basisphenoid and parasphenoid is extensive, limiting that of the orbitosphenoid with the basisphenoid. The presphenoid in its extension upward to the frontal flanks the olfactory lobes and the orifice for the exit of the olfactory nerves on either side, but whether it or the frontal encloses the opening above has not been ascertained.

Proötic (*Prot.*). *Figures 4, 5, 8, and 26.* This cranial element is behind the alisphenoid and in front of the epiotic and opisthotic, neither of which latter, however, are distinguishable as distinct bones in the *Edmontosaurus* skull, both, following the usual rule of cranial development in reptiles, having probably early fused, the epiotic with the supra-occipital and the opisthotic with the exoccipital. Superiorly this bone reaches the parietal, and inferiorly the basi-occipital, and possibly also the basisphenoid to a limited extent.

The proötic is pierced by the foramen for the seventh or facial nerve (VII). In front it completes the opening for the trigeminal nerve behind, and its hinder border is deeply notched by the fenestra ovalis (?+ the fenestra rotunda).

In *Edmontosaurus* (specimen, Cat. No. 2289) the suture between the proötic and the alisphenoid is shown in its upper course. It is seen to leave the foramen ovale high up in the posterior margin of the opening and to ascend, first for a short distance slightly forward, and then for a greater distance backward, to the parietal above. It is clear, therefore, from the position of the suture, that the greater part of the opening is in the alisphenoid as it is in the alligator. In the Jurassic herbivore *Camptosaurus* (Gilmore, 1909, p. 210, fig. 5) the foramen ovale is mostly in the proötic, as it is also apparently in *Triceratops*. Hay in his paper of 1909 on the skull and brain of *Triceratops* remarked that "in *Triceratops* the suture between the proötic and the alisphenoid may be provisionally drawn through the front of the foramen" (foramen ovale).

Superiorly the proötic extends outward from the parietal as part of the floor of the supratemporal fossa. At the outer edge of the floor it is angulated horizontally and overhangs the lower portion of the bone which is concave externally in a vertical direction down to the basisphenoid. This upper angulation or ridge, originating from the proötic, extends horizontally backward, parallel to a similar ridge developed in the opisthotic, and merges posteriorly in the upper face of the paroccipital process of the exoccipital. Between the two ridges the external surface is vertically concave and in this concavity the suture marking the antero-superior boundary of the opisthotic is to be looked for leading upward and backward from the fenestra ovalis. This suture is shown in this position in a cranium of "*Trachodon*" sp. figured by Osborn in 1912 (p. 18, fig. 13, Amer. Mus. No. 427).

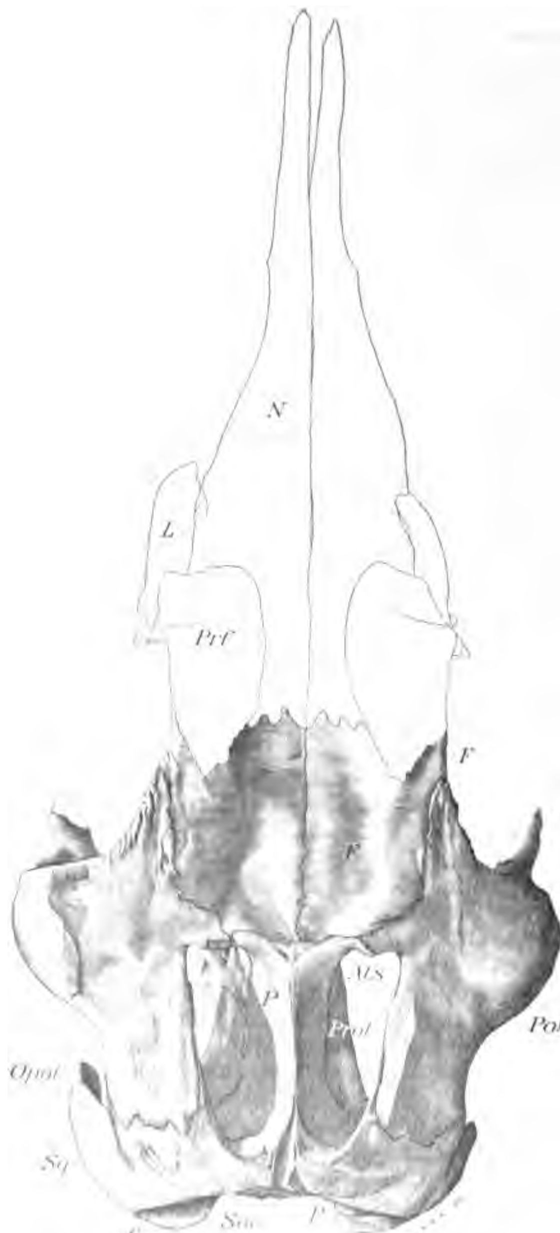


Figure 8. Cranium of Edmontosaurus, Cat. No. 2289; ½ natural size; superior aspect. *Als*, alisphenoid; *F*, frontal; *L*, lachrymal; *N*, nasal; *Opot*, opisthotic; *P*, parietal; *Pof*, postfrontal; *Prf*, prefrontal; *Prot*, proötic; *Soc*, supra-occipital; *Sq*, squamosal.

Parietal (*P.*). *Figures 3, 4, 5, 6, 8, and 26.* This bone, the coalesced parietal pair, forms the roof of the brain-case from behind the cerebrum to the cerebellum, and, in the upper surface of the skull, passes backward from the frontals to the squamosals, separating the supratemporal fossæ. The parietal is longer than broad, narrow for a considerable distance in front of and behind its midlength, and expanded outwardly about equally at either end. Medially it rises between the supratemporal fossæ, with an increasing amount of lateral compression, to the plane of the upper surface of the skull as a high interfossate ridge extremely narrow above. Its lateral faces within the fossæ are concave from below upward.

Supero-anteriorly the parietal meets the frontals to the full extent of their combined posterior breadth in a zigzagged, transverse suture. Antero-externally it is in contact with the postfrontals in a short suture which, leaving the upper surface of the skull, passes down the front margin of the supratemporal fossa and runs forward for a short distance on the lower border of the same, Figure 5, *P*. Posteriorly it meets the squamosals from below in a curved transverse suture about half-way up the posterior face of the supratemporal fossa. In continuation of its median ridge it passes back narrowly, to the occiput separating the squamosals. The upper surface of this intersquamosal portion lies in the general plane of upper surface of the skull and is longitudinally channelled.

The parietal connects inferiorly with the alisphenoid in front, with the proötic farther back, and with the exoccipital behind. The sutural line marking the contact of the lower border of the parietal with the exoccipital and proötic runs forward horizontally in the floor of the supratemporal fossa. Its anterior continuation as the parieto-alisphenoid suture rises with an outward curve and terminates at the postfrontal a short distance in advance of the anterior margin of the supratemporal fossa, see Figure 5, *P—Als*.

The parietal posteriorly in its outward curve within the supratemporal fossa, at a lower level than the squamosal, enters largely into the formation of the posterior face of the opening. Inferiorly it assists the exoccipital, proötic, and alisphenoid in providing a partial floor to the opening. With a small external contribution from the postfrontal it bounds the opening in front.

A narrow, distinctly marked groove, continuous along the summit of the interfossate ridge, apparently marks the original division of the parietal pair.

Measurements of Parietal of Specimen, Cat. No. 2289.

	Mm.
Length along the midline above	198
Maximum anterior breadth within the supratemporal fossæ	150
Maximum posterior breadth	148
Height at midlength	57
Breadth at midlength	62

Squamosal (*Sq.*). *Figures 3, 4, 5, 6, 7, and 8.* This bone is large and with its fellow forms almost the whole of the hinder part of the upper surface of the skull. It bounds the supratemporal fossa posteriorly, enters largely into the formation of the external border of the same, and is in contact with the parietal, postfrontal, quadrate, exoccipital, and ?supra-occipital. It is broadest behind, and medially in front extensively

underlaps the postfrontal. Postero-externally it sends downward and outward a large, laterally compressed process which, narrowing as it descends, curves slightly forward external to the para-occipital process of the exoccipital which supports it along its posterior curve. Postero-internally it extends inward behind the supratemporal fossa and is separated from its fellow only by the narrow, backward extension of the parietal ridge. Infero-externally toward the front it develops a short, stout process which descends with a strong forward and outward inclination on the anterior face of the quadrate. Between this process and the large posterior one the bone is excavated for the reception of the head of the quadrate.

Within the supratemporal fossa in the concavely and upwardly curved posterior face of the opening the squamosal in its inward course is above the parietal, the line of contact between the two bones being at a considerable distance below the plane of the upper surface of the skull. Internally it abuts vertically against the narrow posterior extension of the parietal and completes its enclosure of the supratemporal opening behind by a short forward prolongation on to the median bar.

The forward extension of the squamosal contributing to the formation of the supratemporal arcade is as broad as the portion of the postfrontal to the under surface of which it is applied. It is thin on its inner side and thickens outwardly to the cotylus for the quadrate. It extends forward to near the anterior border of the supratemporal fossa, and its thin inner edge together with the equally thin edge of the postfrontal forms the boundary of the opening externally.

Viewing the skull from above the posterior outline of the squamosals between the pendant process is almost transverse with only a slight curve forward. The squamosal in its upper surface curves slightly downward in its outward course from the parietal. Externally it bends rapidly downward to the descending outer face of the process. Postero-inferiorly the squamosals approach each other closely on either side of the parietal's extremely narrow entry into the occiput. The posterior border of the squamosal for some distance outward from the parietal is heavy and rounded. Farther out, above the exoccipital, it becomes sharp-edged, at first ending freely but in the process closely applied to and coinciding with the par-occipital process. Except along its posterior border the squamosal process is free from the para-occipital process and separated from it by a narrow space.

Measurements of the Squamosal of Edmontosaurus, Paratype, Cat. No. 2289.

	Mm.
Length, from posterior border to anterior termination beneath the postfrontal	195
Breadth, distance obliquely outward and downward from contact with parietal in posterior border to lower end of postero-external process, about	225
Breadth in supratemporal arcade	80
Thickness obliquely upward and outward at midlength of cotylus	50
Interno-posterior thickness (vertical) at contact with parietal	36
Thickness of process at about its middepth and midbreadth	11

Frontal. (*F.*). *Figures 3, 4, 5, 7, 8, 9, 11, and 26.* This element has a rather flat external surface of irregular shape, and longer than broad in about the proportion of 3 to 2. The suture along the midline between the pair is straight and well defined. Posteriorly the bone meets the

parietal, externo-posteriorly the postfrontal, and anteriorly the nasal and prefrontal. Postero-externally it reaches the anterior margin of the supratemporal fossa at about the latter's midbreadth. Externally toward the front it extends outward between the postfrontal and prefrontal, and contributes narrowly to the formation of the orbital rim. The prefrontal and nasal together form an angular emargination of the front border, the extent of contact with the nasal being about one-third of that with the prefrontal. As viewed from below the frontal meets the prefrontal to the full extent of the latter's breadth which is equal to about three-fifths of the breadth of the frontal, the line of suture between the two running transversely inward from the orbital rim with a strongly zigzagged course. Between this contact and the longitudinal midline of the skull the frontal extends forward thinly beneath the nasal to a point nearly as far advanced as the supero-anterior edge of the prefrontal, the full fronto-nasal lapping length being about 111 mm. Beneath the nasals the frontals meet along the midline except for a short distance in front.

Postfrontal. (*Pof.*) *Figures 3, 4, 5, 6, 7, 8, and 26.* The postfrontal is a conspicuous bone of considerable size and is remarkable in that it develops a large fold or pocket subsidiary to the orbital cavity. Seen from above its outline is irregularly triangular with the apex of the triangle directed outward, the long base being greater than either of the other two sides. In lateral aspect its outline may also be said to be roughly triangular with the apex downward.

For one-half its length internally it is in contact with the frontal in a zigzagged suture extending from the centre of the upper curve of the orbital rim to the centre of the anterior margin of the supratemporal fossa. The posterior half of its length internally forms the outer half of the anterior margin of the supratemporal fossa and contributes largely to the formation of the outer margin of that opening. Overlapping the squamosal to near the posterior end of the supratemporal fossa it constitutes with that bone the supratemporal arcade separating the supratemporal from the infratemporal fossa.

Curving outward and downward and narrowing as it descends the postfrontal is gibbous externally to a marked degree and encloses within itself a large pocket which is a backward extension of the orbit and lies exterior to the postfrontal contribution to the postorbital bar. This pocket, opening directly forward, relegates the upper part of the postorbital bar to a position within the orbit, well removed from the exterior surface of the skull. The presence of this pocket occasions modifications of shape in the postfrontal bone, not previously described, so far as the writer is aware, in any known member of the Hadrosauridæ.

The excavation of the postfrontal bone to form the postorbital pocket is extensive, measuring fully 115 mm. in fore-and-aft depth, and leaves the enveloping walls thin, particularly on the inner side, where over a considerable area the bony tissue is only about 1 mm. thick. In the external wall a thickness of from about 4 to 7 or more mm. is attained. In the sweeping inward curve infero-posteriorly the thickness averages about 5 mm. The excavation in its backward extension even enters for a short distance that part of the bone which overlaps the squamosal. Both in the roof and floor of the pocket the bone becomes thicker, especially so in the former on approaching the frontal suture; in the latter the thickening

is most marked toward the front where its downwardly curving front margin is conspicuously furrowed in a fore-and-aft direction. The inner surface of the pocket is everywhere quite smooth.

The outer margin of the pocket is formed by the posterior curve of the orbital rim. The inner wall of the pocket thickens somewhat to the front to form the inner margin which is straight and extends, from a point below and in advance of the antero-exterior curve of the supratemporal fossa, downward and slightly forward, continuing for a short distance below the pocket as a process representing the lower end of the postfrontal contribution to the postorbital bar. This inner margin is external to, and for the whole of its length to near its upper termination is in contact with, the ascending process contributed by the jugal toward the formation of the postorbital bar. Postero-inferiorly the rotundity of the postfrontal encroaches on and considerably lessens the width of the infratemporal fossa in its upper half.

Prefrontal. (*Prf.*). *Figures 3, 4, 6, 8, 9, 10, and, 11.* The prefrontal is about $2\frac{1}{2}$ times as long as broad, and is broader in its anterior half than behind. From being posteriorly in the same horizontal plane with the frontal it curves convexly outward and downward anteriorly to meet the lachrymal and in so doing forms the supero-anterior portion of the orbital rim. It is bounded behind by the frontal, on the inner side extensively by the nasal, in front by the nasal, and below anteriorly for a short distance by the lachrymal. It projects backward into the frontal bone, narrowing about equally from both sides to a point behind. The prefronto-frontal suture is sinuous and both bones are here strong and thick. In front the prefrontal overlaps the downwardly broadened portion of the nasal to a considerable extent, and descending also overlaps the lachrymal. The anterior end is pointed, and downward and backward to the orbit the outline is broadly sinuous. In approaching the orbit from the front the bone curves rapidly outward convexly to the orbital rim. Its lower surface in front of the orbit, at the latter's supero-anterior curve, is excavated, leaving the bone thin with only a slight strengthening at the orbital rim. This excavation is almost circular in outline, roughly 55 mm. in diameter, and about 22 mm. thick, forming a depression facing downward, inward, and slightly backward within the orbit in advance of the orbital rim. Externally above its midbreadth, and about half-way between its anterior end and the orbital rim is a conspicuous foramen which enters the thickness of the bone in front of the inner excavation.

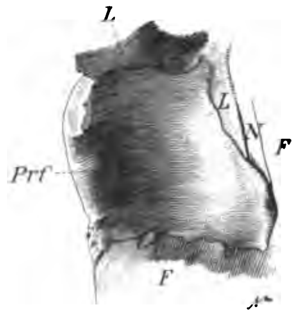


Figure 9. Right prefrontal of Edmontosaurus, Cat. No. 2289; $\frac{1}{3}$ natural size; inferior view obliquely from behind. *F*, frontal; *L*, lachrymal; *N*, nasal; *Prf*, prefrontal.

The area of the inferior surface of this bone is only a little over that of its superior surface, accounted for by the extent to which it overlaps the nasal, lachrymal, and frontal above. Inferiorly the prefrontal presents a deeply concave surface, facing downward, outward, and backward, between the lachrymal in front and the frontal behind. Internally it is bounded by the lachrymal for its anterior half-length, and for the remainder of the length by the nasal and frontal in nearly equal proportions, the contact of the latter, however, being the greater.

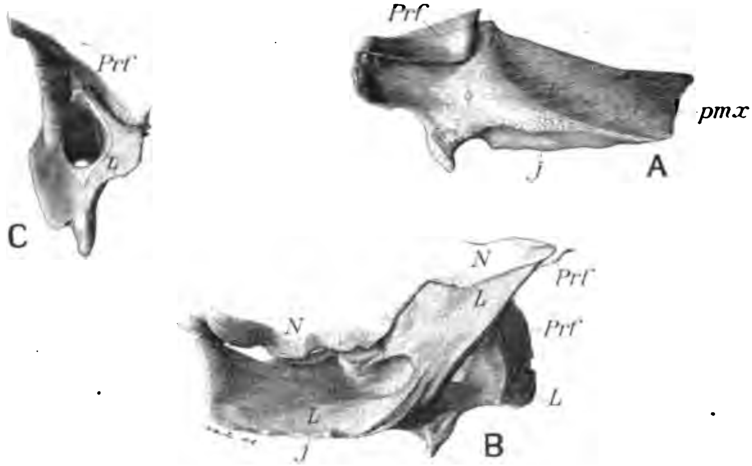


Figure 10. Right lachrymal of Edmontosaurus, Cat. No. 2289; ½ natural size. A, external aspect; B, internal aspect; C, posterior aspect; *L*, lachrymal; *N*, nasal; *Prf*, prefrontal; *j*, surface for contact with jugal; *pmx*, with premaxillary.

Lachrymal (L.). Figures 3, 4, 5, 8, 9, 10, and 11. This bone is over twice as long as high, and somewhat wedge-shaped, being thickest behind and thin toward the front. It is in contact with the nasal, prefrontal, jugal, maxillary, and premaxillary. When in position in the skull its length is in the direction of that of the lower premaxillary limb.

Viewing the lachrymal in position from without it presents a surface with an irregularly four-sided outline broadest behind and pointed in front. Supero-anteriorly it is largely hidden beneath the termination of the premaxillary limb. It is overlapped supero-posteriorly by the prefrontal for a considerable distance. Inferiorly it unites for the whole of its length with the jugal. The posterior border comes to a sharp edge which is decidedly protrudent outward in its upper part. This border is free and forms that portion of the orbital rim between the prefrontal and the jugal where it projects backward into the orbit to a considerable extent. The lachrymal contribution to the orbital rim is mostly below the midheight of the orbit. Postero-inferiorly, at the back end of the jugal contact, it extends a stout, pointed process downward behind the jugal. The external surface is somewhat convex in a direction at right angles to its length.

In the disarticulated skull, Cat. No. 2289, this bone is still firmly attached to the nasal and prefrontal, but the jugal, maxillary, and lower premaxillary limb are separate from it so that its true shape and the full extent of the majority of its surfaces are revealed. The bone ends abruptly in front with little decrease in depth forward. Outwardly the surface covered by the premaxillary limb supero-anteriorly is large, equal in area to about one-half of the entire external surface. The outer overlap of the prefrontal above is small, as is also that of the jugal below.

The inner surface of the lachrymal, revealed in the disarticulated skull, is interesting. Toward its posterior end the bone is greatly thickened

is most marked toward the front where its downwardly curving front margin is conspicuously furrowed in a fore-and-aft direction. The inner surface of the pocket is everywhere quite smooth.

The outer margin of the pocket is formed by the posterior curve of the orbital rim. The inner wall of the pocket thickens somewhat to the front to form the inner margin which is straight and extends, from a point below and in advance of the antero-exterior curve of the supratemporal fossa, downward and slightly forward, continuing for a short distance below the pocket as a process representing the lower end of the postfrontal contribution to the postorbital bar. This inner margin is external to, and for the whole of its length to near its upper termination is in contact with, the ascending process contributed by the jugal toward the formation of the postorbital bar. Postero-inferiorly the rotundity of the postfrontal encroaches on and considerably lessens the width of the infratemporal fossa in its upper half.

Prefrontal. (*Prf.*). *Figures 3, 4, 5, 8, 9, 10, and, 11.* The prefrontal is about 2½ times as long as broad, and is broader in its anterior half than behind. From being posteriorly in the same horizontal plane with the frontal it curves convexly outward and downward anteriorly to meet the lachrymal and in so doing forms the supero-anterior portion of the orbital rim. It is bounded behind by the frontal, on the inner side extensively by the nasal, in front by the nasal, and below anteriorly for a short distance by the lachrymal. It projects backward into the frontal bone, narrowing about equally from both sides to a point behind. The prefronto-frontal suture is sinuous and both bones are here strong and thick. In front the prefrontal overlaps the downwardly broadened portion of the nasal to a considerable extent, and descending also overlaps the lachrymal. The anterior end is pointed, and downward and backward to the orbit the outline is broadly sinuous. In approaching the orbit from the front the bone curves rapidly outward convexly to the orbital rim. Its lower surface in front of the orbit, at the latter's supero-anterior curve, is excavated, leaving the bone thin with only a slight strengthening at the orbital rim. This excavation is almost circular in outline, roughly 55 mm. in diameter, and about 22 mm. thick, forming a depression facing downward, inward, and slightly backward within the orbit in advance of the orbital rim. Externally above its midbreadth, and about half-way between its anterior end and the orbital rim is a conspicuous foramen which enters the thickness of the bone in front of the inner excavation.

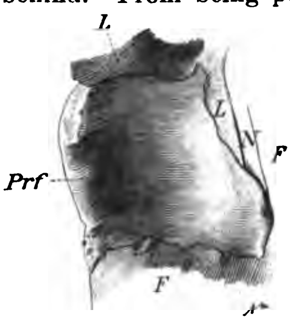


Figure 9. Right prefrontal of Edmontosaurus, Cat. No. 2289; ⅓ natural size; inferior view obliquely from behind. *F*, frontal; *L*, lachrymal; *N*, nasal; *Prf*, prefrontal.

The area of the inferior surface of this bone is only a little over that of its superior surface, accounted for by the extent to which it overlaps the nasal, lachrymal, and frontal above. Inferiorly the prefrontal presents a deeply concave surface, facing downward, outward, and backward, between the lachrymal in front and the frontal behind. Internally it is bounded by the lachrymal for its anterior half-length, and for the remainder of the length by the nasal and frontal in nearly equal proportions, the contact of the latter, however, being the greater.

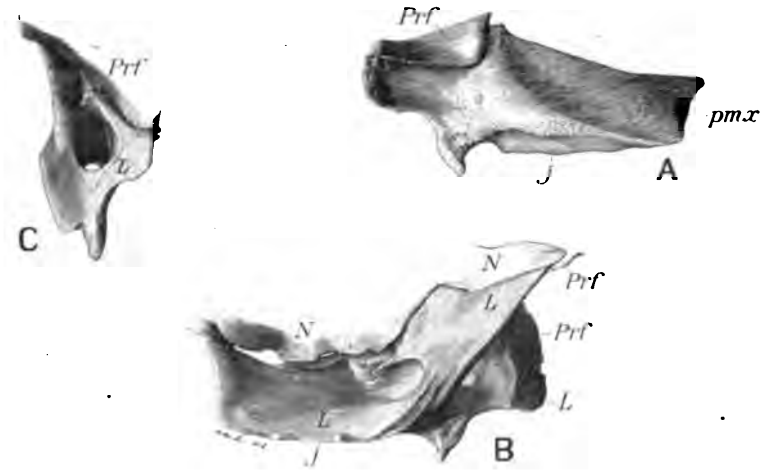


Figure 10. Right lachrymal of Edmontosaurus, Cat. No. 2289; ½ natural size. A, external aspect; B, internal aspect; C, posterior aspect; *L*, lachrymal; *N*, nasal; *Prf*, prefrontal; *j*, surface for contact with jugal; *pmx*, with premaxillary.

Lachrymal (*L.*). *Figures 3, 4, 5, 8, 9, 10, and 11.* This bone is over twice as long as high, and somewhat wedge-shaped, being thickest behind and thin toward the front. It is in contact with the nasal, prefrontal, jugal, maxillary, and premaxillary. When in position in the skull its length is in the direction of that of the lower premaxillary limb.

Viewing the lachrymal in position from without it presents a surface with an irregularly four-sided outline broadest behind and pointed in front. Supero-anteriorly it is largely hidden beneath the termination of the premaxillary limb. It is overlapped supero-posteriorly by the prefrontal for a considerable distance. Inferiorly it unites for the whole of its length with the jugal. The posterior border comes to a sharp edge which is decidedly protrudent outward in its upper part. This border is free and forms that portion of the orbital rim between the prefrontal and the jugal where it projects backward into the orbit to a considerable extent. The lachrymal contribution to the orbital rim is mostly below the midheight of the orbit. Postero-inferiorly, at the back end of the jugal contact, it extends a stout, pointed process downward behind the jugal. The external surface is somewhat convex in a direction at right angles to its length.

In the disarticulated skull, Cat. No. 2289, this bone is still firmly attached to the nasal and prefrontal, but the jugal, maxillary, and lower premaxillary limb are separate from it so that its true shape and the full extent of the majority of its surfaces are revealed. The bone ends abruptly in front with little decrease in depth forward. Outwardly the surface covered by the premaxillary limb supero-anteriorly is large, equal in area to about one-half of the entire external surface. The outer overlap of the prefrontal above is small, as is also that of the jugal below.

The inner surface of the lachrymal, revealed in the disarticulated skull, is interesting. Toward its posterior end the bone is greatly thickened

inward by a strong ridge which proceeds upward and slightly backward, from the hinder end of the jugal contact, and ends thinly above between the prefrontal and the nasal at a much higher level than the postero-external limit of the bone above. In this inner thickening is a large perforation which leads forward, from the concave, interorbital posterior face of the bone, through to the free internal surface which is vertically concave, the amount of concavity decreasing forward. The thin apical portion of the maxillary fits closely from below within the lachrymal in the latter's anterior half, and continues downward the internal concavity of the lachrymal. In the description of the maxillary mention has already been made of the double foraminal opening below the internal concavity of its apex. This concavity passing from the lachrymal to the maxillary marks the course of the lachrymal canal from the large perforation in the lachrymal to the above-mentioned maxillary foramen which latter apparently connects obliquely forward and downward with the large external foramen in the maxillary situated in advance of the anterior end of the lachrymal and almost hidden by the lower border of the premaxillary limb. The internal maxillary foramen also leads backward and connects with an opening in the deep, vertical groove which is present behind the base of the apical portion of the maxillary.

In describing the type skull of *Gryposaurus*[1] the writer mentions the posterior opening of the lachrymal canal which has a position similar to that in the present genus.

Measurements of Right Lachrymal of Specimen Cat. No. 2289 (disarticulated skull).

	Mm.
Extreme external length, in a straight line	180
Extreme external depth	80
Posterior opening of lachrymal canal—	
Vertical diameter	40
Transverse diameter	23

Figure 11. Right nasal of Edmontosaurus, Cat. No. 2289; internal aspect, obliquely from below; ½ natural size. *F*, frontal; *L*, lachrymal; *mx*, surface for maxillary; *N*, nasal; *pmx*, surface for upper limb of premaxillary; *Prf*, prefrontal.

Nasal (N.). Figures 3, 4, 5, 8, 9, 10, and 11. The nasal bone is long and narrow and is in contact with its fellow along the longitudinal midline of the skull except for about one-fourth of its length in front where the two are separated by the upper premaxillary limbs. It is slender for the whole of its length except in the anterior half of its posterior half-length where

[1]The Ottawa Naturalist, vol. XXVII, 1914.

it is relatively broad. Posteriorly it is in contact with the frontal which it overlaps to some extent. In its narrow posterior part it bounds the prefrontal inwardly, then suddenly expanding it extends downward in front of the prefrontal to the lachrymal and the posterior end of the lower premaxillary limb. Its contact with the lachrymal is short but it meets the premaxillary limb for a distance slightly over one-third of the latter's length. Becoming slender again it passes forward above the narial opening to meet the upper premaxillary limb and continuing forward exterior to that process it ends thinly with a rounded outline just beyond the anterior end of the opening. Along the length of its contact with the premaxillary limb the nasal thins gradually to the front in the same ratio that the premaxillary limb narrows to its posterior termination, thus providing a uniform transverse breadth to the premaxillo-nasal portion of the roof of the narial opening. Behind the termination of the upper premaxillary limb the lower border of the nasal becomes decidedly protrudent, flatly arched at first and then descending backward, as the bone rapidly expands, to the lower premaxillary limb. Retired inward from the lower end of this protrudent border a spur of bone is sent forward by the nasal within the upper edge of the premaxillary limb, and in contact with the maxillary, increasing the extent of the naso-premaxillary contact and completing the enclosure of the posterior end of the narial opening within the nasal bone as seen in lateral aspect.

Premaxillary. (*Pmx.*). *Figures 3 and 4.* This bone consists of an anterior portion expanding horizontally outward, a long, backwardly directed, gradually narrowing lower limb, and a relatively short upper limb also directed backward. As viewed externally it is in contact with the nasal, the lachrymal, and the maxillary. The two premaxillaries together give an anterior breadth to the snout apparently little less than the maximum breadth of the skull behind. The lower limb bounds the narial opening inferiorly for three-fourths of the latter's length, and continuing beyond the posterior end of the opening, overlapping both the nasal and the lachrymal, it terminates some distance short of the prefrontal. The upper limb passing back with increasing tenuity on the inner side of the nasal assists it in the formation of the supranarial bar to a point at about the midlength of the opening. The anterior end of the narial opening is within the premaxillary. As seen from above the front margin of the premaxillary curves outward and backward for about one-fourth of the bone's total length; the outline is then inward and backward concavely in participation of the transverse compression of the skull at and above the maxilla. The front border of the anterior expansion of the premaxillary is recurved for some distance so as to roof over an extensive cavity which opens backward. The bone throughout is thin so that what outwardly might appear to be a heavy ending to the snout is in reality greatly lightened. The floor of the cavity is smooth and is continued backward as an extensive, more or less depressed tract which is subdivided into three principal areas two of which together occupy the breadth of the bone at the mouth of the cavity and lead from it, and the third is situated beneath the narial opening. The inner anterior area is the most sunken of the three, is the least extensive, and is separated from the other two by a flange of bone which passes downward and slightly forward from the base of the upper limb in continuation of the upper

margin of the narial opening. The outer anterior area, occupying the remainder of the bone's breadth, is bounded externally by the raised inwardly retreating border of the expanded snout. It is not so sunken as the first but becomes moderately deep outwardly. It is marked off from the subnarial area by a sharply defined difference in the amount of depression in the two. The third or subnarial area is much longer than broad, occupies the entire breadth of the lower limb, and extends at either end slightly past the narial opening. Its depressed surface, which is deepest anteriorly, has an outline that, taken in conjunction with that of the opening, forms an irregular, lengthened oval. Its curved posterior demarcation continues downward the marginal protrudence of the nasal already referred to as occurring at the posterior end of the narial opening.

Maxillary. (*Mx.*). *Figures 3, 4, 12, and 13.* This element is slightly over two and a half times as long as high and in lateral aspect has roughly the outline of an isosceles triangle of which the base, represented by the straight

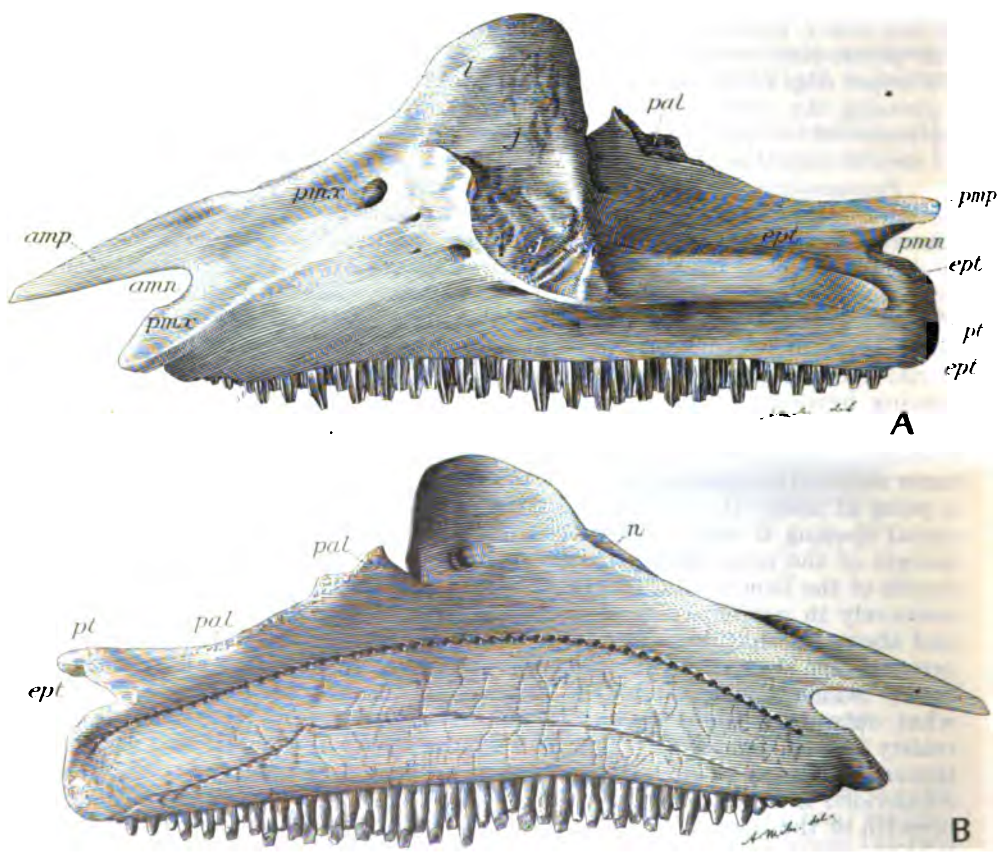


Figure 12. Left maxillary of Edmontosaurus, Cat. No. 2289; ¼ natural size. A, view from without; B, view from within. *amn*, anterior maxillary notch; *amp*, anterior maxillary process; *ept*, surface for ectopterygoid; *j*, for jugal; *l*, for lachrymal; *n*, for nasal; *pal*, for palatine; *pmn*, posterior maxillary notch; *pmp*, posterior maxillary process; *pmx*, surface for lower limb o premaxillary; *pt*, for pterygoid.

alveolar border, is much longer than the sloping sides, which descend concavely from a broadly curved apex. It is laterally compressed and thin above, and thick along its lower length. The inner face is as a whole rather flat in great contrast to the varied relief of the outer one. Externally the bone is most protrudent, and thickest, at about midlength at a distance above the alveolar border equal to about one-sixth of its maximum height. From here extends upward the rugose surface of attachment of the front end of the jugal, the bone thinning rapidly upward. From the lower, overhanging edge of the surface for the jugal a robust ridge runs horizontally backward with diminishing strength to near the end of the bone. The surface between the ridge and the alveolar border is vertically concave. In advance of the surface for the jugal the external face is tumid upward from the alveolar border until on approaching the antero-superior border it becomes vertically concave in a marginal depressed area in which lay the ascending lower limb of the premaxillary. This area gains in width and in the amount of its concavity as it proceeds forward causing the anterior end of the bone to be thin-edged in front and sharply angulated supero-externally. Another concave area, still more pronounced in its depression, occurs in the posterior half of the bone between the shell-like upper surface of the ridge and the postero-superior border. Unlike the anterior concave area this posterior one is widest next to the surface for the attachment of the jugal and diminishes rapidly backward leaving the hinder end of the bone thick and robust. The bone is thin in the apical region, presents a flatly convex surface outward, and is sharp-edged above. Anteriorly this apical surface descends into

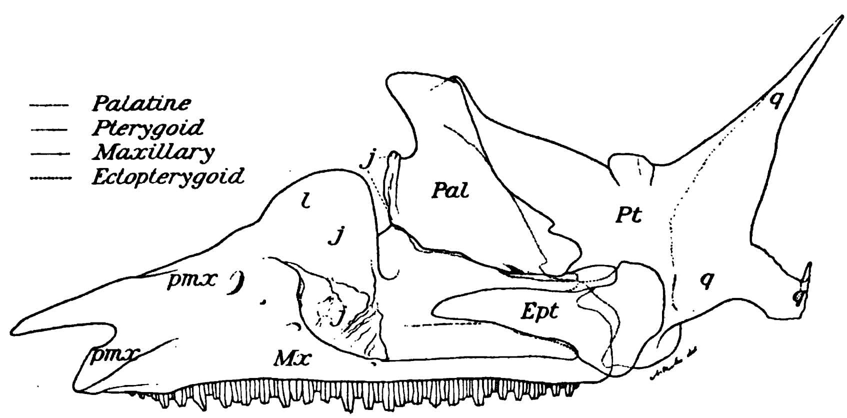


Figure 13. The left maxillary, palatine, pterygoid, and ectopterygoid of Edmontosaurus, Cat. No. 2289, in position relative to each other to show extent of contact; ¼ natural size; external aspect. *Ept*, ectopterygoid; *Mx*, maxillary; *l*, surface for lachrymal; *j*, surface for jugal; *Pal*, palatine; *pmx*, surface for lower limb of premaxillary; *Pt*, pterygoid; *q*, surface for quadrate.

the antero-superior marginal depression for the reception of the premaxillary limb; posteriorly it is separated from the postero-superior concave area by a deep, vertically directed groove which emarginates the superior border behind the apex. The antero-superior portion of the apical surface is in close contact with the inner surface of the lachrymal. Below the lachrymal contact the surface for the attachment of the jugal

passes downward, becoming concave and more rugose in its lower part with a sudden increase in the thickness of the bone. The surface for the jugal is roughly semicircular in outline with the curve forward.

The antero-superior border of the maxillary is transversely narrow and is furnished with a smooth, shallow groove in which lay the infero-posterior process of the nasal directed forward below the hinder end of the nasal opening. In continuation forward of this border is a laterally compressed process (anterior maxillary process) which extends considerably beyond the main lower termination of the bone and is separated from it by a deep emargination (anterior maxillary notch). The postero-superior border of the maxilla is also narrow and supplies a very rugose sutural surface for the attachment of the lower edge of the palatine. In continuation backward of this border occurs a posterior process between which and the heavy, rounded end of the bone is a posterior notch of smaller proportions than the anterior one. The postero-maxillary process receives in contact internally the pterygoid as the latter passes forward to lap within the palatine. It is grooved below for the upper border of the ectopterygoid in such a manner that its termination lies external to and on the ectopterygoid. The posterior notch is filled by the thickened portion of the ectopterygoid. The postero-external surface below the notch is rugose, curves convexly down to the level of the alveolar border and receives in close contact the ectopterygoid and below it the pterygoid, the latter being overlapped by the former. The posterior end of the maxillary ridge is bounded above and behind by a groove into which fits the lower border of the ectopterygoid where it begins its rapid posterior expansion.

Although the inner face of the maxillary is flat as a whole in comparison with the outer one, the apical region is decidedly hollowed out, and there is a shallow concavity of the surface extending from the anterior end back past midlength. A conspicuous feature of this face is a flatly arching row of small, circular foraminal openings extending below the midheight of the bone from points above the first and last teeth. There is one foramen to each vertical series of teeth. Between these dental foramina and the alveolar border is a well-defined vascular groove of the same length and with nearly the same curve as the foraminal row. In the lower portion of the apical concavity are two foramina, one large, the other small, placed close together and leading downward.

There are fifty-one to fifty-three vertical series of maxillary teeth occupying seven-eighths of the total length of the bone, the dental magazine terminating closer to the posterior than to the anterior end. The external and internal alveolar borders are at the same level.

Exteriorly two large foramina occur beneath the protrudent base of the surface for the attachment of the jugal, and one, even larger, is present considerably in advance of the same surface near the superior border. In the same general region are other small openings disposed as shown in Figure 12. Special reference is made to the maxillary teeth under another heading (page 55).

Measurements of Left Maxillary of Edmontosaurus, Cat. No. 2289.

	Mm.
Maximum length, about	436
Length at level of alveolar borders	422

Height at midlength	180
Length of dental magazine	368
Breadth across alveolar borders at midlength	24
Breadth at lower edge of surface for attachment of jugal	70
Maximum protrusion of teeth below alveolar border at midlength of dental magazine	33

Jugal. (*J.*). *Figures 3, 4, and 14.* This element is long, thin, and plate-like, with an obtusely angulated lower outline, and deep indentations above forming the lower boundaries of the orbital and infratemporal openings. Its extreme length to its maximum depth is in about the proportion of 6 to 5. It connects antero-superiorly with the lachrymal and palatine, anteriorly with the maxillary, posteriorly with the quadrato-jugal and the quadrate, and superiorly considerably behind its midlength with the postfrontal by means of its ascending process behind the orbit. Externally it interjects a forwardly directed angulation of the front border

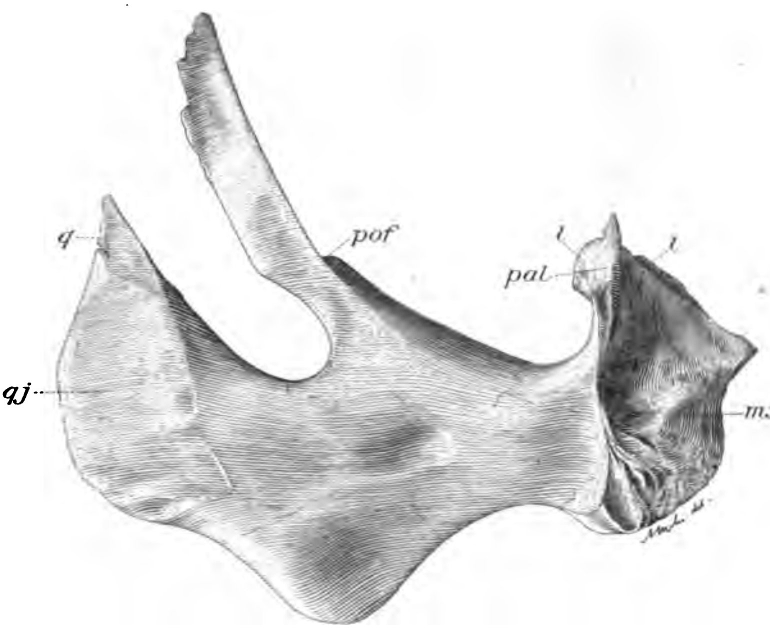


Figure 14. Left jugal of Edmontosaurus, Cat. No. 2289; internal aspect; ½ natural size. *l*, surface of contact with lachrymal; *mx*, with maxillary; *pal*, with palatine; *q*, with quadrate; *qj*, with quadrato-jugal; *pof*, with postfrontal.

between the lower end of the lachrymal and the highest point of the maxillary to the lower edge of the premaxillary limb. The anterior end of the jugal covers the maxilla behind the latter's midlength in an extensive rugose surface of contact. Antero-superiorly it is grooved in a longitudinal direction, more deeply near the orbit than toward the front, to receive the lower edge of the lachrymal. The superior border is deeply emarginated by the narrow, somewhat similarly curved, downwardly and forwardly directed lower ends of the orbit and infratemporal fossa. The ascending

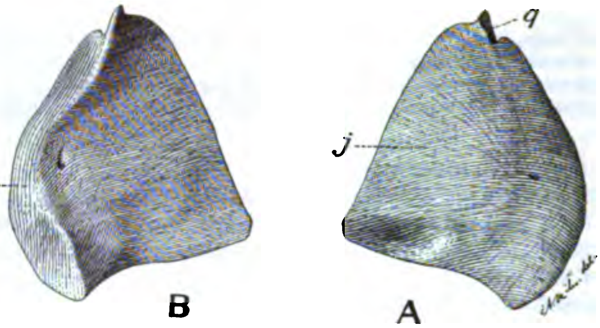


Figure 15. Left quadrato-jugal of Edmontosaurus, Cat. No. 2289; ½ natural size. *A*, outer aspect; *B*, inner aspect; *j*, surface of contact with jugal; *q*, with quadrate.

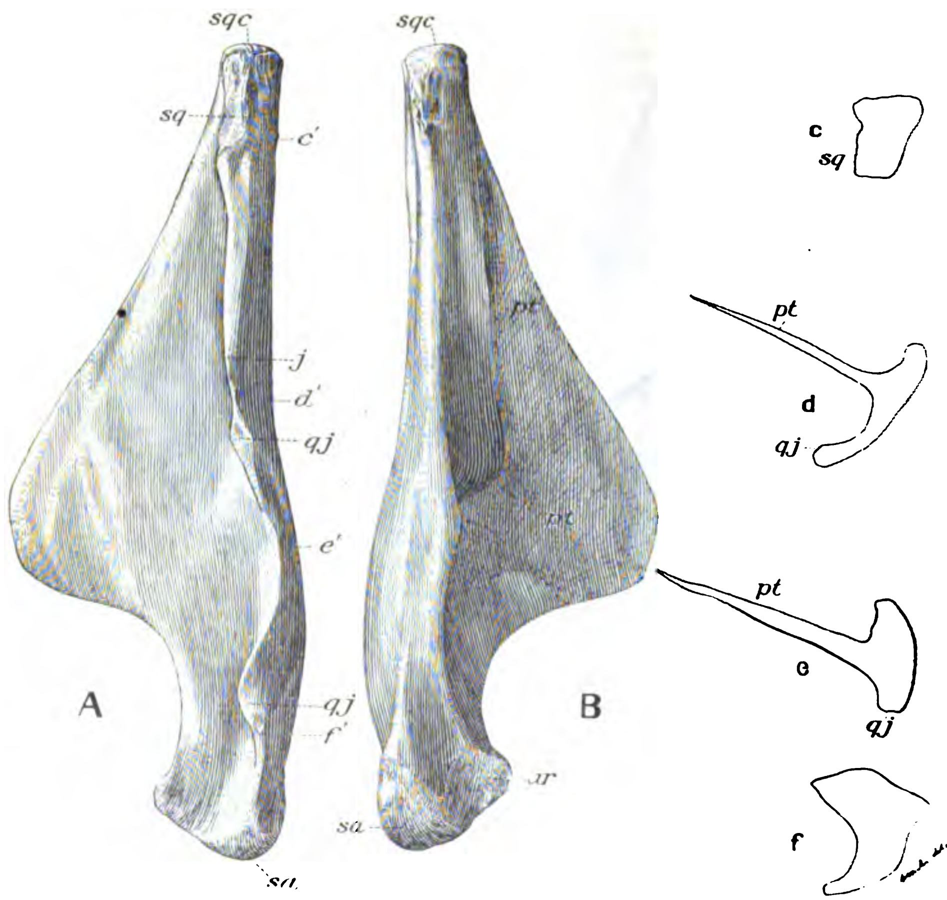


Figure 16. Left quadrate of Edmontosaurus, Cat. No. 2289; ½ natural size. A, external view obliquely from the front; B, internal view obliquely from behind; *c*, *d*, *e*, *f*, outlines of transverse sections at *c'*, *d'*, *e'*, *f'*, respectively. *ar*, surface for articular; *j*, for jugal; *qj*, for quadrato-jugal; *pt*, for pterygoid; *sa*, for surangular (mandibular cotylus); *sq*, for squamosal; *sqc*, received in squamosal cotylus.

process, contributing to the formation of the postorbital bar, is particularly long and slender and passes up on the inner side of, and in a long contact with, the short descending process of the postfrontal and the front border of the inner wall of the postfrontal pocket. Posteriorly the jugal extensively covers the quadrato-jugal and abuts against the outer front border of the quadrate for some distance above the quadrato-jugal.

Quadrato-jugal. (*Qj.*). *Figures 3, 4, and 15.* This bone is a thin subtriangular plate, slightly higher than long, highest anteriorly and longest near the base. Its front border is straight, the lower one nearly so but undulating, and the posterior one curved forward above. It thins to the front border which is approximately vertical when the bone is in position. More than one-half of the external surface is covered by the jugal in a close, rather smooth contact lacking the numerous inequalities of the junction of the jugal with the maxillary. Posteriorly the quadrato-jugal narrowly overlaps the quadrate whose antero-external border is emarginated to receive it. A groove is developed in the border behind the apex into which the front border of the quadrate above its emargination fits.

Quadrate. (*Q.*). *Figures 3, 4, and 16.* This bone consists of a transversely compressed bar from whose inner surface a large, thin flange is directed inward and forward. It connects with the quadrato-jugal and jugal antero-externally, with the pterygoid internally by means of the flange, with the squamosal superiorly, and with the surangular and articular inferiorly. It occupies an almost vertical position in the skull with the head immovably fitted into the pit in the squamosal, and with the lower end in the mandibular cotylus.

Viewed from without it is narrowest above, and bent slightly forward from either end so as to have an evenly concave posterior outline. Below the midlength the anterior border is broadly but shallowly emarginated for the reception of the narrowly overlapping posterior curve of the quadrato-jugal. The anterior border starting from the head, with the latter's transverse thickness, becomes thin in its descent to the quadrato-jugal overlap where it thickens to some extent, but is again thin for a short distance above the lower end of the bone. In its upper part the quadrate presents a flattened surface facing outward but with a slight obliquity inward and backward, and the posterior border is obtusely angulated. Approaching midlength the external surface, with an increasing obliquity, twists inward so as to form a face directed nearly backward and ends inwardly in a narrow border which is the downward continuation of the upper posterior angulation. At the lower end the posterior surface is again angulated.

The inwardly and forwardly directed flange of the quadrate is given off from the inner surface of the main portion. Its base extends the whole length of the bone and is situated, in the lower half, about midway between the front and back borders, but toward the top it passes nearer to the back border. The flange is thin, triangular in lateral outline, and reaches its greatest protrusion in line with the centre of the quadrato-jugal contact

or about two-thirds of its length from the upper end. Above the lower end it rises rapidly with a concavely curved edge to its apex whence it ascends less rapidly with a nearly straight edge to the head. Throughout it partakes of the general curve of the main portion of the bone so that its interno-posterior face is concave. Between the base of the flange and the incurved anterior border the inner surface of the bone is concave; a concavity equally deep but extending for a shorter distance above and below the midlength occurs behind the flange between its base and an incurve of the posterior border.

The lower end of the quadrate has its greatest diameter transverse and fits into the mandibular cotylus jointly contributed to by the surangular and the articular. When seen from below it is subtriangular in outline with the apex of the triangle inward, the base convex outward, and the sides concave. The larger outer part of the lower surface is convex and faces directly downward in contact with the surangular, the inner and smaller apical portion of the surface is almost flat, looks downward and backward, and fits against the articular, the combined facets being the quadrate's contribution to the mandibular hinge. The inner articular extension of the lower end acts as a pedestal for the ascending flange.

A roughened surface on the inner front of the bone, extending for a short distance downward from the head, marks the close sutural contact of the short, stout process or spur descending from the squamosal in advance of the pit in that element into which the head of the quadrate fits.

Above the narrow, curved surface which marks the overlap of the quadrato-jugal, a limited, roughly striated area on the inner side of the anterior border indicates the surface of contact with the jugal.

The extent of the overlap by the pterygoid is well marked on the postero-internal face of the flange by a surface which extends downward from the top of the flange for more than two-thirds of its length. This surface extends over the flange from its edge and is roughened by striations which are approximately at right angles to the free edge. At its lower end it broadens abruptly below a conspicuous sunken area in the inner posterior marginal concavity already described.

The head of the quadrate in an undetermined species of Trachodon has elsewhere[1] been referred to as movable in the cotylus of the squamosal. There can be no doubt that it was firmly fixed in position and immovable in the genus now under description. The fact that a heavy process from the squamosal descended for some distance on and suturally united with the anterior border of the quadrate below its head is sufficient to prove that the quadrate was stable at its upper end. The very extensive lapping contact between the quadrate and the pterygoid would in itself be sufficient to prevent any movement of the former element. The direct contact of the jugal with the quadrate was slight and can have added little to the strength of the close union of the jugal with the quadrato-jugal, and the latter with the quadrate.

[1]Memoirs of the American Museum of Natural History, new series, vol. I, pt. I, "Crania of Tyrannosaurus and Allosaurus," by Henry Fairfield Osborn, 1912, p. 18, fig. 13.

Measurements of Quadrate of Edmontosaurus (paratype, Cat. No. 2289).

	Mm.
Length of quadrate in a straight line	420
Maximum breadth (antero-posterior) of external surface above contact with quadrato-jugal	93
Horizontal distance from external surface to greatest extension inward of flange connecting with pterygoid	145

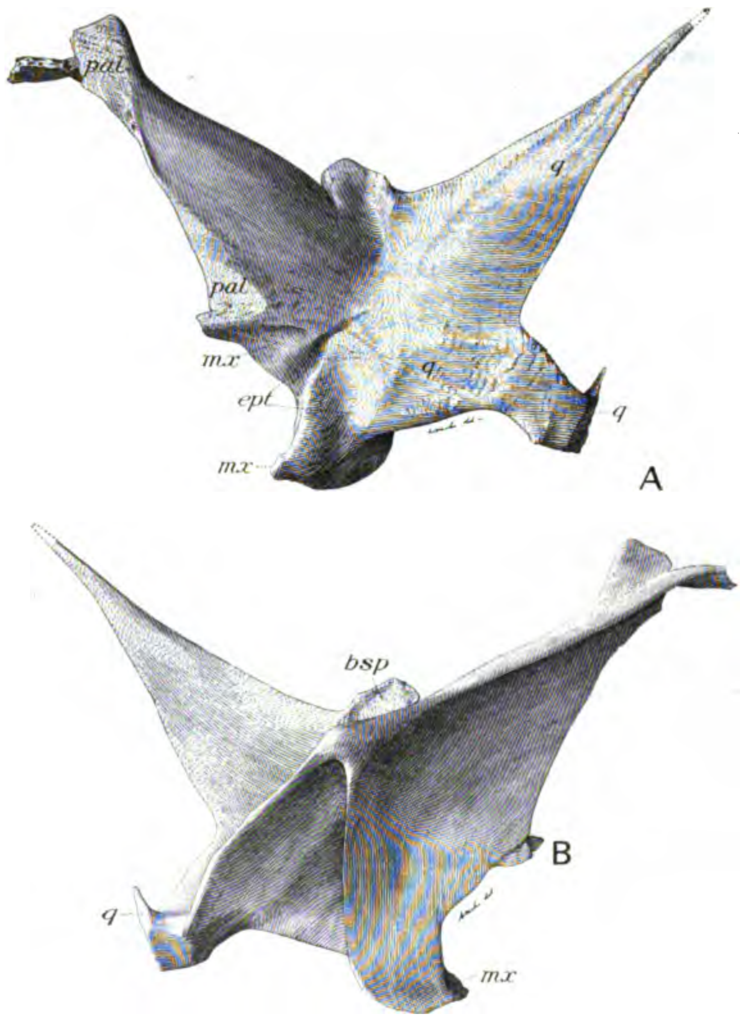


Figure 17. Left pterygoid of Edmontosaurus, Cat. No. 2289; ¼ natural size. A, external aspect; B, internal aspect; *bsp*, surface of contact with process of basisphenoid; *ept*, with ectopterygoid; *mx*, with maxillary; *pal*, with palatine; *q*, with quadrate.

Pterygoid. (*Pt.*). *Figures 3, 13, and 17.* The pterygoid is a thin bone of complicated shape in contact with the quadrate, basisphenoid, palatine, maxillary, and ectopterygoid. It probably also effects a junction supero-anteriorly with the vomer.

In lateral aspect it is roughly four-sided in outline, longest, and deeply and angularly concave above, and sinuous in front and behind with a convergence downward to the comparatively short base which is broadly and shallowly concave.

It consists of a plate-like main portion from which is given off an antero-superior alar extension and a postero-superior alar extension directed upward and forward and upward and backward respectively. Internally the bone is strengthened by two large flanges which are united above and diverge downward to opposite ends of the base.

The alar extensions, or wings, are both broad-based and narrow rapidly upward. The posterior one is flat, continues in the plane of the main portion of the bone and ends in a slender point. The anterior one leaves the general plane of the outer face, the contained external angle approaching 130 degrees. It is curved at right angles to its length presenting a transversely convex surface facing backward and upward, and, as the bone is thin, its lower, front surface is transversely concave.

Of the internal flanges the posterior one is the larger and the stouter of the two. It is carried backward and inward in much the same general line of direction as the upper part of the anterior wing, in fact a prolongation backward of the superior border of the wing forms the joint apical portion of the converging flanges. The more anterior and thinner flange is also directed backward but more inward than the larger one, and its inner anterior surface is a continuation backward of the inner concavity of the anterior wing. The two flanges partition the bone internally into three unequal areas; an anterior one, the largest, consisting of the moderately shallow, inner concavity of the anterior wing and its backward continuation by the anterior flange; a median one, the smallest of the three, deeply confined between the upwardly converging flanges; and a posterior one deeply but more openly enclosed by the posterior flange and the posterior wing.

The sutural union of the pterygoid with the quadrate is extensive and is effected by the application of the external face of the former to the inner face of the flange of the latter, the surface of contact on the pterygoid extending forward from the full height of its posterior border so as to include nearly the whole of the wing area and the lower portion of the bone to a short distance in advance of its inferior midlength. The slender upper end of the wing reaches up to within a short distance of the head of the quadrate, the front border of the wing and that of the flange of the quadrate being coincident for some distance down. The posterior border of the wing below its slender upper termination comes to a thin edge. Below the wing the posterior border thickens to some extent, is rugose and is applied to a ridge on the face of the flange of the quadrate. Still farther down the postero-inferior angle of the bone becomes stout, is roughened, and fits into the narrow concavity between the posterior border of the quadrate, where it is angularly most protrudent, and the base of the flange.

The pterygoid meets the maxillary in two small, separate surfaces, viz., one, infero-anteriorly where the bone curves outward and forward over the lower portion of the posterior end of the maxillary and ends pointedly, the other, a short distance higher up, where the anterior margin passes forward on the inner side of the posterior process of the maxillary.

Between this second surface for maxillary attachment and the lower part of the overlap of the flange of the quadrate is the moderately large surface for the external application of the posterior expansion of the ectopterygoid. Above the contact with the maxillary process, for the full height of the anterior wing of the pterygoid, is the surface for the palatine which passes externally back over the pterygoid for a varying distance from its anterior border.

At the midlength of the superior border, between the wings, facing inward and backward, and occupying the upper end of the posterior, internal enclosure between the posterior flange and the posterior wing is a rugose, concave surface, oval in outline, which grasps the front lower convexity of the process of the basisphenoid.

The forward end of the anterior wing of the pterygoid is not complete, but here the bone thickens slightly downward and supplies a roughened narrow surface, directed forward and facing inward, which apparently indicates the union with the back termination of the vomer.

Measurements of Left Pterygoid of Edmontosaurus, Cat. No. 2289.

	Mm.
Maximum length above (imperfect antero-superiorly)	357
Maximum length below	184
Maximum vertical, anterior height above base-level	268
Maximum vertical, posterior height above base-level	217
Vertical height, above base-level, of superior border behind surface of contact with basisphenoid process	149

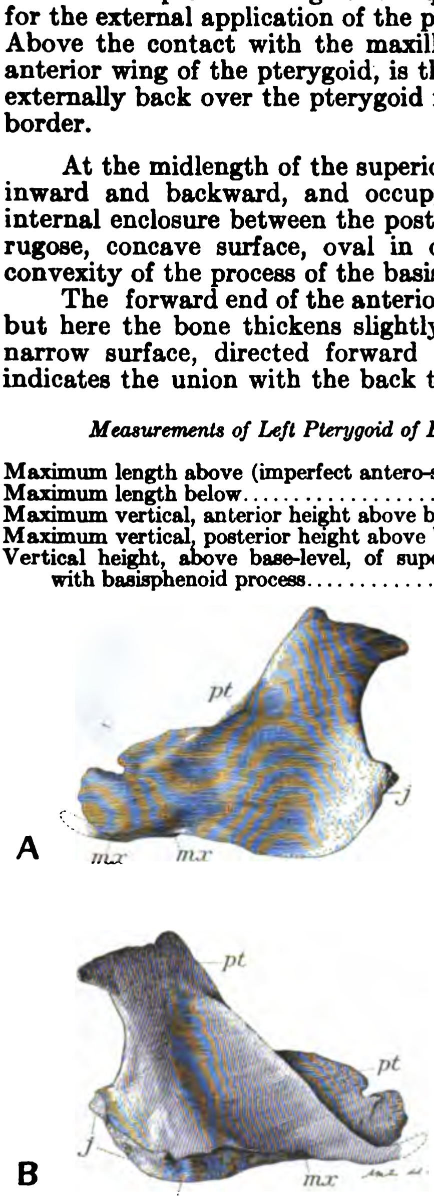


Figure 18. Right palatine of Edmontosaurus, Cat. No. 2289; ½ natural size. A, outer aspect; B, inner aspect; *j*, surface of contact with jugal; *mx*, with maxillary; *pt*, with pterygoid.

Palatine. (*Pal.*). *Figures 3, 13, and 18.* This element is somewhat triangular in lateral outline, is highest near the front and narrows downward and backward to the nearly straight base. It is thin and plate-like and when in position is almost vertical above the postero-superior border of the maxillary. It is suturally united to the maxillary, the jugal, and the pterygoid. The anterior border is shallowly emarginated in its upper half to form the posterior curve of the posterior nares. In the lower half of the border is a roughened sutural surface facing forward and slightly outward and downward for contact with the jugal in the infero-anterior angle of the orbital rim. This surface has an irregularly oval outline and is about twice as high as broad. Behind its contact with the jugal the palatine fits on the narrow postero-superior border of the maxillary back to and extending slightly on to the posterior maxillary process. From here

forward and upward, to the upper end of the front border, it outwardly overlaps the pterygoid, the amount of overlap being greatest toward the front and back diminishing to a simple narrow contact at the midlength of the overlap. The bone thickens near the maxillary suture, and is strengthened interno-anteriorly by a smooth ridge which beginning as a thickening of the anterior emargination passes down to the lower border. Behind this ridge the inner surface is broadly and shallowly concave. In advance of the ridge the bone bends outward and spreads transversely to form the jugal surface of contact. In the foremost part of its contact with the maxilla the palatine extends downward to some extent on the outer surface of the maxillary border. Infero-posteriorly the palatine develops a thin, laterally compressed, backwardly directed process between which and the main termination of the bone the border of the pterygoid ascends to its lapping contact with the palatine. Antero-superiorly the palatine apparently does not reach the vomer, the pterygoid intervening.

	Mm.
Maximum height of right palatine	134
Maximum length of same, measured horizontally within vertical lines, about	185

Ectopterygoid. (*Ept.*). *Figures 13 and 19.* This bone is closely applied externally to the maxilla and pterygoid with its length in an antero-posterior direction. It is about twice as long as high and is thin and overlapping except in a small inwardly thickened area which fits into the postero-maxillary notch, and comes between the maxilla and pterygoid in sutural contact with both. In lateral outline it is broadest behind, narrows rapidly forward for one-third of its length, and is continued narrowly forward to its anterior end. Its external surface is gently undulating. Its anterior two-thirds of length lies closely in the postero-external concave area of the maxilla on and above the shelf formed by the horizontal ridge extending back from the maxillo-jugal surface of contact. The upper and lower borders of the bone, where it begins to broaden posteriorly, fit into two grooves in the maxillary, one in the lower surface of the postero-maxillary process, the other curving downward round the posterior end of the maxillary ridge. Here the bone thickens inwardly below the superior border and fills the maxillary notch, underlapping also the maxillary process internally to a slight extent. Below the thickened part the inner face of the bone is excavated to fit closely over the upper convexity of the posterior end of the maxillary. Posteriorly the bone broadly overlaps the pterygoid.

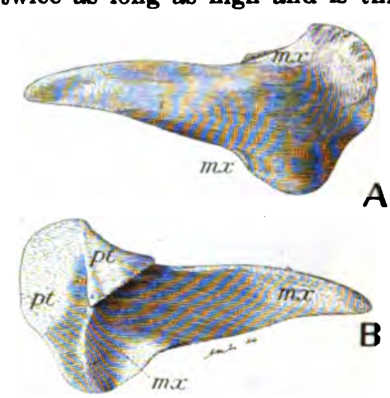


Figure 19. Left ectopterygoid of Edmontosaurus, Cat. No. 2289; ½ natural size. A, outer aspect; B, inner aspect; *mx*, surface of contact with maxillary; *pt*, with pterygoid.

Measurements of Left Ectopterygoid of Specimen, Cat. No. 2289.

	Mm.
Estimated length	192
Estimated maximum breadth (height) posteriorly	100
Thickness of bone where it fills the postero-maxillary notch	23
Average thickness of bone elsewhere	6

Vomer. (*V.*). *Figure 3.* This element is known only from a small portion disclosed toward its anterior end in the specimen collected in 1912 (Cat. No. 2288). The vomer has not been found with the disarticulated skull, belonging to the skeleton collected in 1916. It apparently, however, connected in front with the maxillaries on the inner side of the anterior maxillary processes, and behind with the pterygoids on the interno-superior surface on the height of their anterior wings, and had an estimated length of 385 mm.

The portion of the vomer seen in the 1912 specimen is 125 mm. long, attains a maximum breadth of 20 mm., and lies in the midline of the skull in the posterior half-length of the narial opening on a level with and midway between the upper border of the lower premaxillary limbs. It is broadest at midlength, narrows slightly forward and much more so backward, so as to have an anterior breadth of 16 mm. and a posterior one of 6 mm. In front it ends abruptly in a transverse break so that the shape of the bone at the maxillary connexion is not revealed. Behind, it continues into the matrix of which as much has been removed as is at present possible. Toward the front what appears to be a median line of division, traceable for a short distance back, suggests a coalescence of an elemental pair.

The vertical inner surface of the laterally compressed anterior maxillary process in *Edmontosaurus* is rugose along the whole of its length in advance of a narrow, horizontal, shelf-like protrusion, projecting inward from the hinder part of the process, for the support of the vomer from beneath. That the vomer passed forward beyond the anterior maxillary processes is probable judging from the appearance of the inner surface of these processes which are rugosely striated to the tip. In *Prosaurolophus* a shallow groove is present on the inner side of the superior border of the lower premaxillary limb beneath the anterior end of the narial opening and just behind where the lower limbs separate for their backward ascent. This groove in *Prosaurolophus* marks the position of the attenuated anterior end of the vomer, and it is probable that the vomer of *Edmontosaurus* had a like slender termination in advance of the maxillæ. To all appearances, therefore, the vomer remained narrow between the anterior processes of the maxillaries, separating them from each other by only a short transverse distance.

The shape of the posterior termination of the vomer is unknown. On the inner side of the narrowly compressed ridge forming the most elevated part of the pterygoids forward is a roughened, transversely concave surface on which the posterior end of the vomer apparently lay. Whether the vomer bifurcated behind and reached the pterygoids on either side of the median line in this manner, or united with the pair by a horizontal expansion has not been ascertained as yet. Judging, however, from the distance apart of the pterygoids anteriorly the vomer had a posterior breadth of about 50 mm. Its estimated breadth between the forward end of the anterior maxillary processes is about 10 mm. In this genus the vomer appears, therefore, to have been slender throughout and devoid of any considerable expansion.

Mandible. (*Figures 3 and 20.*) The mandible of *Edmontosaurus* is extremely long. The converging rami meet in a short horizontal symphysis and are embraced in front by the unpaired predentary bone. The rami are deepest at their midlength, and attain their maximum breadth at about two-thirds of their length from the front where the conspicuously high coronoid process is developed. In lateral aspect they have a nearly straight or slightly undulating inferior outline. As seen from above they are bow-shaped with an inward bend at midlength, and an incurve at either end abrupt in front where they meet, and less so behind where they are some distance apart. Each ramus consists of a dentary, which is edentulous for about three-eighths of its length in front, a surangular, an angular, a splenial, an articular, and possibly a prearticular, but whether this element is certainly present had not been ascertained. The dentary forms the greater part of the

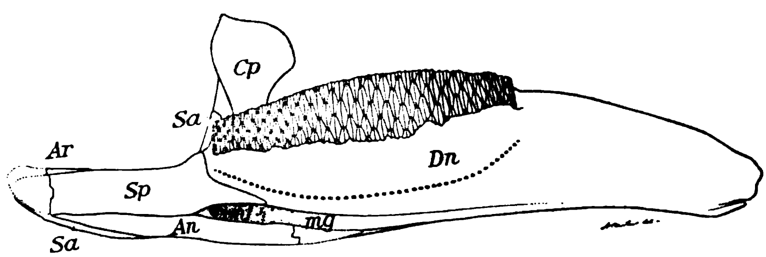


Figure 20. Left mandibular ramus of Edmontosaurus, Cat. No. 2289, viewed from the inner side; ⅙ natural size. *An*, angular; *Ar*, articular; *Cp*, coronoid process; *Dn*, dentary; *mf*, mandibular fossa; *mg*, Meckelian groove; *Sa*, surangular; *Sp*, splenial.

ramus. Of the other comparatively small elements, composing the hinder end of the ramus, the surangular is robust and much the largest, the angular is long and slender, and the articular the smallest. The splenial and the angular together make up the greater part of the inner surface of the ramus posteriorly. The surangular supplies the lower and outer surfaces at the hinder end. The articular lies above the surangular between it and the splenial and to a limited extent is exposed externally above the surangular. The dental magazine is nearer the posterior than the anterior end of the ramus, and is for the most part in the dentary's posterior half-length. The edentulous portion of the dentary is only slightly less than one-third of the length of the ramus.

The cotylus by means of which the mandible articulates with the quadrate is far back at a very short distance in advance of the angle of the jaw. It is provided principally by the surangular, but the articular also, to a small extent, enters interno-superiorly into its formation. The mandibular fossa is of large size and is confluent in front with the Meckelian groove which latter extends forward inferiorly on the inner surface of the dentary. The fossa is enclosed externally by the coronoid process of the dentary and the surangular, inferiorly by the dentary and the surangular, and internally by the dentary, splenial and angular. Antero-internally it opens inward through a long, narrow vacuity (internal mandibular foramen) occurring between the angular below, and the splenial and dentary above.

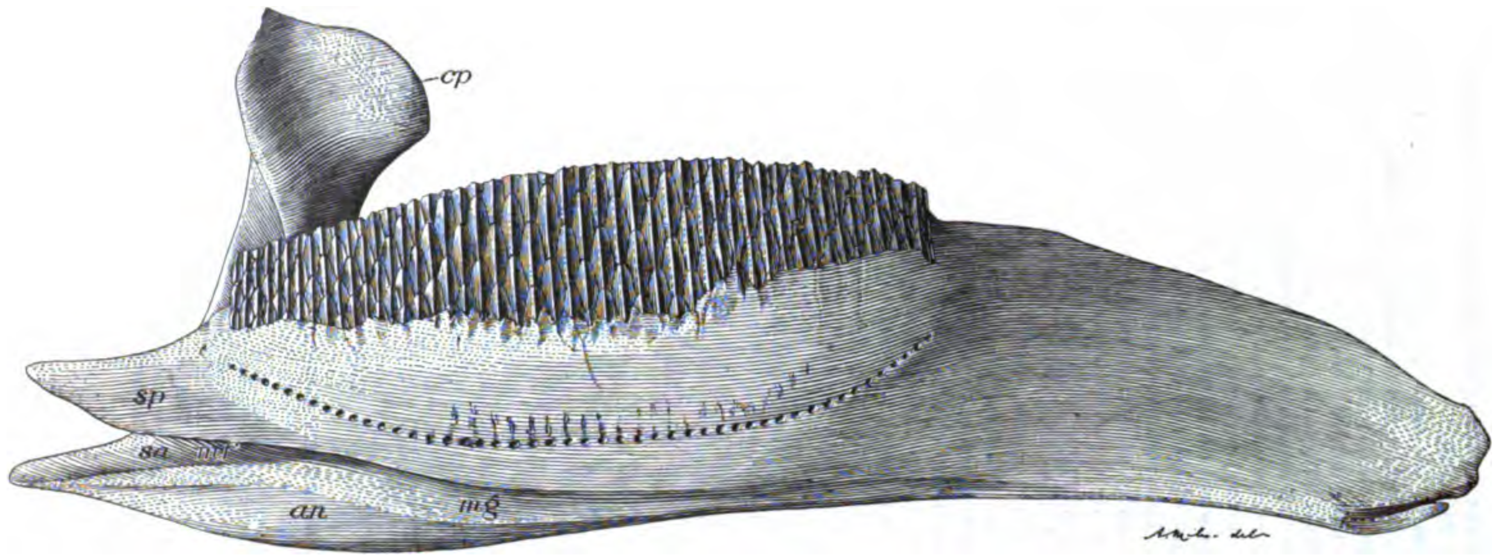


Figure 21. Left dentary of Edmontosaurus, Cat. No. 2289; ½ natural size; inner view. *an*, surface for angular; *cp*. coronoid process; *mf*, mandibular fossa; *mg*, Meckelian groove; *sa*, surface for surangular; *sp*, for splenial.

The surangular anteriorly overlaps the thin lower posterior termination of the dentary, the excavation of the anterior portion of its upper surface forming the hinder part of the floor of the mandibular fossa. Its slender antero-exterior prolongation or limb fits closely against and runs high up on the inner side of the posterior border of the coronoid process. An impressed area of triangular outline, narrowing backward, on the lower

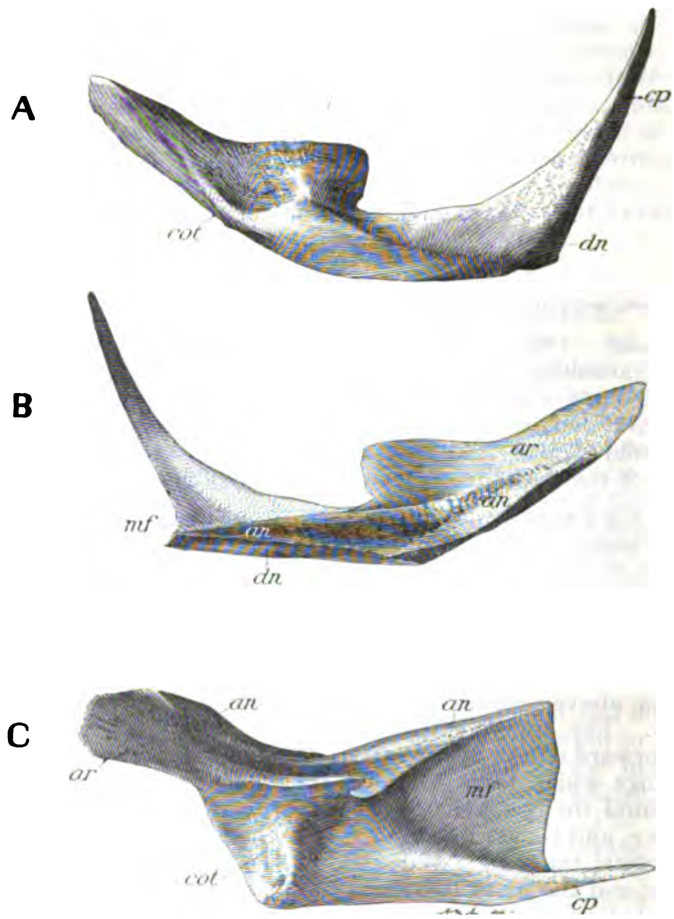


Figure 22. Right surangular of Edmontosaurus, Cat. No. 2289; ¾ natural size. A, external aspect; B, internal aspect; C, superior aspect; *an*, surface for angular; *ar*, surface for articular; *cot*, cotylus for distal end of quadrate; *cp*, surface for coronoid process; *dn*, for dentary; *mf*, mandibular fossa.

surface of the bone in its anterior half, and continuing upward as a decided flattening of the limb on its outer side, marks the full extent of the contact of the surangular with the dentary. The inner backward extension is closely applied from beneath to the articular which, in its more posterior part, is between this extension of the surangular and the splenial, and

which apparently passes forward on the inner side of the flange and is supported below by the narrow horizontal shelf between the base of the flange and the sutural surface for the angular.

The upper surface of the bone externo-posteriorly is shallowly excavated for the reception of the greater portion of the lower end of the quadrate, the remaining part of the cotylus being supplied by the articular. The contribution given to the cotylus by the surangular passes inward and upward on to the flange and is defined in front by a low, rounded ridge which runs transversely outward from the flange near its anterior ending to the outer border slightly in advance of the postero-exterior angle of the main portion of the bone.

Measurements of Right Surangular of Edmontosaurus, Cat. No. 2289 (disarticulated skull).

	Mm.
Length of bone measured along the curve of its lower surface from the front border to the termination of the posterior extension	290
Breadth at midlength	81
Height at midlength from lower surface to top of median flange	69
Backward extension of surangular beyond infero-posterior termination of dentary	147
Thickness, from lower to upper surface, of main portion of midbreadth slightly behind midlength	31

Articular. (*Ar.*). *Figures 20 and 23.* In this species the articular is as yet imperfectly known. In the type skull, Cat. No. 2288, it is represented in the right mandibular ramus by a small fragment in place between the surangular and the splenial above the posterior termination of the angular. In the disarticulated skull, Cat. No. 2289, the only part of it

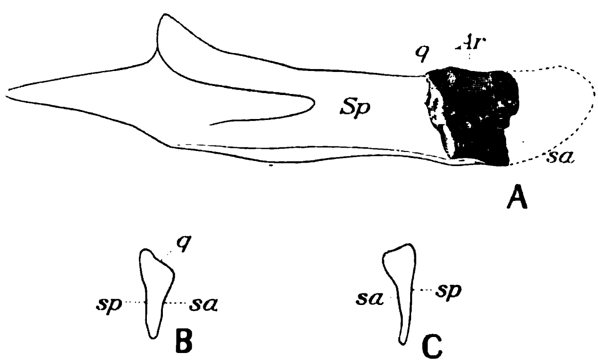


Figure 23. Portion of left articular of Edmontosaurus, Cat. No. 2289, in place on the splenial; ½ natural size. A, external aspect; B, anterior aspect in outline; C, posterior aspect in outline. *Ar*, articular; *q*, surface for contact with quadrate; *sa*, surface for surangular; *Sp*, splenial; *sp*, surface for splenial.

remaining is a piece of irregular shape, 55 mm. in maximum length, 51 mm. in depth behind, and 21 mm. in breadth antero-superiorly, adhering to and in its proper relative position to the outer posterior surface of the left splenial as shown in Figure 23. The fragment in the type skull, so far as its smallness permits, corroborates the larger portion in the second skull as regards shape and position.

The portion of the articular preserved in the disarticulated skull, although imperfect behind and possibly in front gives the depth and thickness of the bone apparently where it is stoutest. It is thinnest below and rises on its inner side slightly above the upper border of the splenial. Outwardly it displays a flattened surface directed obliquely downward, for attachment to the surangular, and having a depth equal to about two-thirds of the total depth of the bone. Above this surface is the remaining one-third of the depth of the bone directed outward, and supplying a free surface which in its anterior part is slightly concave and constitutes the small contribution of the articular to the mandibular cotylus. The narrow lower border of the articular fits into the groove in the surangular mentioned in the description of that bone as occurring above the posterior end of its surface for the attachment of the angular. Continuing backward the articular probably rose still higher above the upper border of the splenial, as restored in Figure 20, reliance being placed to some extent on the shape of the articular in *Gryposaurus*. The articular in advance of its contribution to the cotylus, in view of the fact that there is a space left between the splenial and the surangular when these bones are in position, may have continued forward as a moderately thin bone between the inner vertical face of the flange of the surangular and the concave outer surface of the splenial, and supported below by the horizontal shelf of the surangular. However, the possibility of the presence of a prearticular should not be overlooked.

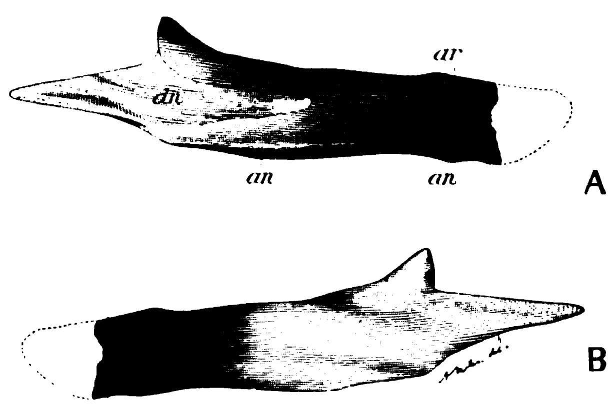


Figure 24. Left splenial of Edmontosaurus, Cat. No. 2289; ½ natural size. A, outer view; B, inner view; *an*, surface for angular; *ar*, surface for articular; *dn*, surface for dentary.

Splenial. (Sp.). Figures 20 and 24. This element is a moderately thin plate of bone of about the same general thickness as the angular but deeper and shorter, and is in contact with the angular, the dentary, and the articular, inferiorly with the angular, antero-externally with the dentary, and postero-externally with the articular.

It is deepest at about one-third of its length from the front where a thin process, developed from the superior border, curves outwardly over the supero-internal termination of the dentary behind the dental magazine.

In advance of the curved process the bone narrows to a point. In the posterior two-thirds of its length it lessens but slightly in depth backward. In each of the three splenials available for study, viz., the two belonging to the naturally disarticulated skull, Cat. No. 2289, and the right one of Cat. No. 2288, the posterior end is missing, but, judging principally from the shape of the surangular in this region, it probably terminated with a rounded lateral outline as restored in the above figure. The bone is curved in conformity with the curve of the angular and surangular so that its inner surface is moderately concave in a longitudinal direction.

Its superior border toward the front rises over, as already stated, and embraces the upper edge of the dentary. Its pointed anterior extension reaches forward and is applied to the dentary below the hindermost portion of the row of dental foramina. The surface of contact with the dentary extends slightly back of the splenial's half-length.

The splenial reaches farther back than the angular and is in contact inferiorly with it for nearly the whole of the latter's half-length. The surface of contact between the two is broadened and, with the increase in area, strengthened by a ridge which extends outward along its length causing the lower external surface of the bone to be decidedly concave in a vertical direction. The upper surface of this ridge receives, and supports from below, at least in its more posterior part, the lower border of the articular. Anteriorly there is a space left between the splenial's pointed extension and the angular which leads outwardly into the mandibular fossa. Postero-externally the bone for the whole of its depth is applied to the articular and passes beneath it by means of the ridge just mentioned.

Measurements of Left Splenial of Edmontosaurus, Cat. No. 2289 (disarticulated skull).

	Mm.
Length of bone preserved, measured along the inner curve	250
Estimated total length	304
Depth at midlength	50
Length of sutural surface of contact with dentary	172
Maximum breadth of same	16

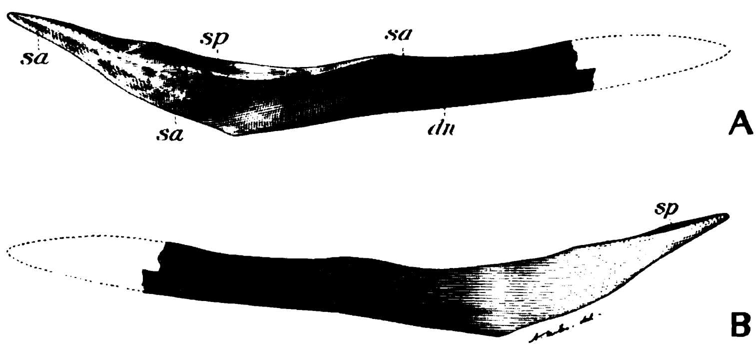


Figure 25. Right angular of Edmontosaurus, Cat. No. 2289; ¼ natural size. A, external aspect; B, internal aspect; *dn*, surface for dentary; *sa*, for surangular; *sp*, for splenial.

Angular. (*An.*). *Figures 20 and 25.* This bone is long, narrow, and thin, and is in sutural contact with the splenial, the surangular, and

the dentary. It runs forward from a short distance in advance of the hinder end of the surangular, on the inner side of that bone, to a point on the dentary below the Meckelian groove, presumably about in line with the midlength of the dental magazine. In lateral aspect it is bent at one-third of its length from the posterior termination, being straight and inclined slightly upward in the hinder part, and horizontally straight in the two-thirds forward length. Its greatest depth is at the bend whence it narrows forward and backward to its pointed ends. Viewed from above it has a flattened sigmoid curve resulting from its close application posteriorly to the convex curve of the inner border of the surangular, and anteriorly to the longitudinal concavity of the lowermost inner surface of the dentary. Superiorly, for nearly the whole of its posterior half-length, it is in contact with the lower border of the splenial. In Figure 25B, representing the inner aspect of the right angular, the surfaces of contact of the bone with the three elements above mentioned are clearly indicated.

Measurements of Right Angular of Edmontosaurus, Cat. No. 2289 (disarticulated skull).

	Mm.
Length of bone preserved, measured along the inner curve	290
Estimated total length	377
Depth at bend	37
Maximum horizontal breadth of sutural surface for surangular (max. thickness)	15

Outer Openings of Skull.

Supratemporal Fossæ. These openings are of moderate size, and very close together on either side of the extremely narrow longitudinal parietal ridge. They are subtriangular in outline, more than twice as long as wide, narrowly rounded behind, and end squarely in front where they are widest. They are bounded externally by the postfrontal and squamosal (supratemporal arcade), posteriorly by the squamosal, anteriorly by the postfrontal and parietal, and internally by the parietal and squamosal. They are floored on their inner side by the parietal, proötic, and to a limited extent also toward the front by the alisphenoid. Infero-externally they open beneath the supratemporal arcade into the infratemporal fossæ, and are confluent infero-anteriorly with the orbital cavities.

Infratemporal Fossæ. The principal feature of these openings is their extreme narrowness in comparison with their height. Although narrow below they become still further reduced in their upper half where they are encroached on by the backward extension of the large postfrontals. Their lower end is within the jugal. Anteriorly the fossæ are bounded by the post-orbital bar proper and the augmented postfrontal; their narrow upper end is confined by the postfrontal and squamosal, and posteriorly their margin is formed by the squamosal, quadrate, and jugal. They are nearly twice as long as the supratemporal fossæ.

Orbital Cavities. The orbits are the largest of the openings of the skull, the next in size being the narial opening. They are subcircular in outline with an antero-inferior extension downward and forward, the height slightly exceeding the length at midheight. The anterior margin is formed by the prefrontal, lachrymal, and jugal. Superiorly the opening is bounded by the prefrontal, frontal, and postfrontal, posteriorly by the

postfrontal and jugal, and inferiorly by the jugal. The relative sizes of the orbits, narial opening, infratemporal fossæ, and supratemporal fossæ, may be expressed by the numbers 86, 56, 25, and 24 respectively.

Post-temporal Fossæ. In the occiput a deep transverse indentation or groove runs outward on either side from beneath the backward extension of the parietals under the lower border of the squamosal. This groove for some distance beneath the squamosal (Figure 6) represents the post-temporal fossæ reduced vertically to such an extent as to be virtually closed. In its more external part the lower border of the squamosal has an arched curve above the groove. Inferiorly the groove is bounded by the proötic and ?supra-occipital. A somewhat similar condition of these fossæ is found in Iguanodon.[1]

Narial Opening. This opening has the form in lateral outline roughly of a lengthened oval, somewhat flattened below, and more rounded in front than behind, with a length nearly five times the height. The anterior and posterior ends are within the premaxillary and the nasal respectively. The superior margin is formed almost wholly by the nasal, and the inferior one principally by the premaxillary. The size of the opening is proportionate to the great anterior development of the premaxillaries.

Foramen Magnum. This opening is large in comparison with the size of the brain-cavity. Its width is equal to half that of the cavity at the cerebrum and about equal to that across the medulla. It is nearly oval in outline, higher than wide, and narrowed slightly below. The vertical diameter is 50 mm. and the horizontal one at midheight about 40 mm. It is bounded below by the basi-occipital, laterally by the exoccipitals, and above apparently by the supra-occipital. Its upper outline is sharply defined by the transverse angulation formed by the junction of the descending roof of the brain-cavity and the lower surface of the supra-occipital. Laterally and inferiorly its exact boundary is not so clearly marked—being carried backward over the basi-occipital and between the condylar protrusions of the exoccipitals. Viewing the cranium from behind the opening is set deeply in the occiput with the supra-occipital extending nearly horizontally backward for a distance of fully 115 mm. from its upper rim.

Cranial Foramina. Figures 26 and 27. The openings in the brain-case for the exit of the various nerves are well preserved in the paratype *of Edmontosaurus.* Their size and position are as depicted in Figure 26 giving an external view from the right of the cranium proper. In Figure 27 showing the cast of the brain-cavity in three aspects, lateral (A), superior (B), and inferior (C), the length of the foramina and their direction through the cranial walls are indicated.

The olfactory nerve opening (I) is bounded inferiorly and externally by the presphenoid. Whether the opening is roofed over by the frontals, or by the presphenoid, or by both, has not been determined as no sutures giving the desired information are preserved. The side walls of the presphenoid seem to curve inward over the opening, in which case the frontals would contribute to the formation of the roof only along the longitudinal midline. The opening is more than twice as wide as high.

[1] Quatrième note sur les dinosauriens de Bernissart, par M. L. Dollo, Bull. Musée Royal d'Histoire Naturelle de Belgique, tome II, 1883, pp. 224–248, pls. IX and X.

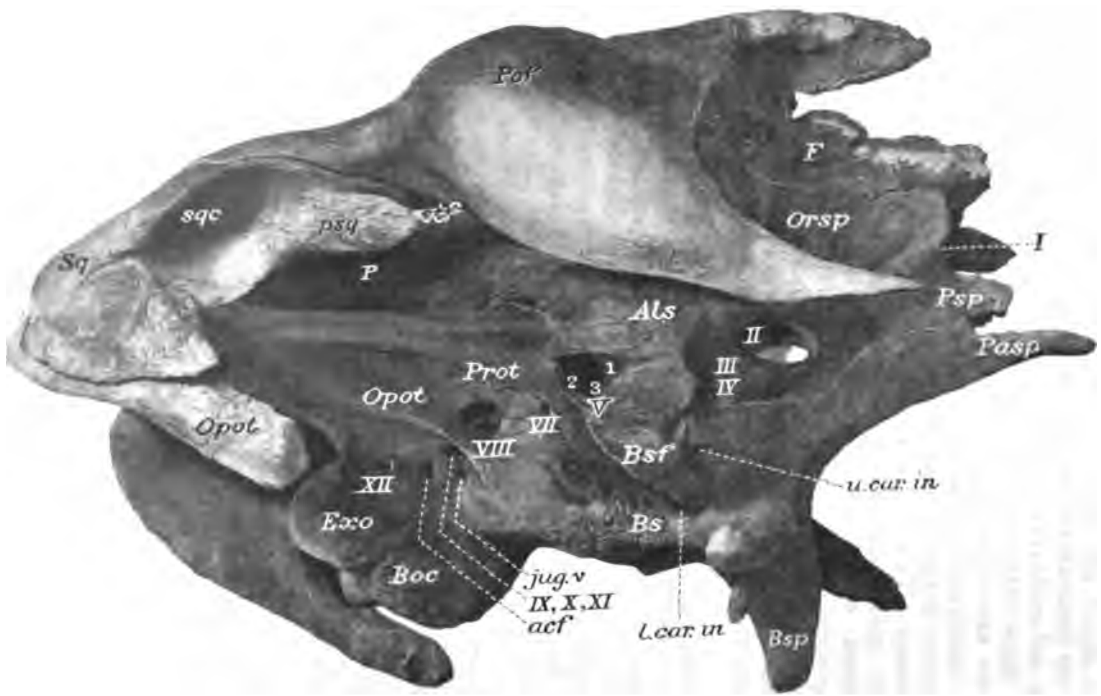


Figure 26. Brain-case of Edmontosaurus, Cat. No. 2289; ½ natural size; right lateral aspect. ***acf.*** anterior condylid foramen; *Als*, alisphenoid; *Boc*, basi-occipital; *Bs*, basisphenoid; *Bsf*, flange of basisphenoid; *Bsp*, process of basisphenoid; *Exo*, exoccipital; *F*, frontal; *jug. v.*, foramen for jugular vein; *l. car. in*, lower (posterior) foramen for internal carotid artery; *Opot*, opisthotic; *Orsp*, orbitosphenoid; *P*, parietal; *Pasp*, parasphenoid; *Pof*, postfrontal; *Prot*, proötic; ***Psp***, **presphenoid**; *psq*, process of squamosal; *sq*, squamosal; *sqc*, squamosal cotylus; *stf*, supratemporal fossa; *u. car. in*, upper (anterior) foramen for internal carotid artery; I, II, III, IV, V, VII, VIII, IX, X, XI, and XII, exits of cranial nerves.

Its outline, as seen from the front, is flat below with a slight, abrupt rise at midwidth, rounded at either side, and broadly lowered medially above, so that the height is least at the middle, indicating the position of the olfactory lobes, one at either side.

Piercing the cranium from side to side where it is narrowest in the lower part of the orbitosphenoids is a passage of considerable size vertically in line with the anterior end of the basisphenoid. This passage occupied by the optic chiasma also communicates widely upward with the brain-cavity through the floor below the space for the cerebrum; it is in advance of, and at a slightly higher level than the pituitary fossa with which it is confluent behind. The external openings of the passage are oblique to the longitudinal axis of the skull, and set at an angle to each other, approaching each other in front, and facing decidedly downward and forward. They are oval in outline and nearly twice as long as high. The median opening above is 30 mm. wide transversely. It was by means of the lateral openings that the optic nerves (II) found exit.

Behind and at a slightly lower level than the transverse perforation just described, and separated from it by a bar of bone about 14 mm. broad, is a large, almost circular foramen apparently for the common exit of the oculomotor (III) and trochlear (IV) nerves. It occurs in the back part of the decided concavity marking the lateral compression of the lower, front portion of the brain-case, It opens through the upper part of the side walls of the pituitary cavity (infundibulum) its upper curve being about on a level with the posterior rim of the pituitary fossa. Running forward from the lower margin of the foramen is the suture defining the upper limit of the front part of the basisphenoid. Whether this opening is wholly within the alisphenoid, or, as its position suggests, bounded behind by the alisphenoid and in front by the orbitosphenoid has not been determined, complete coalescence between these two elements having apparently taken place.

Behind the foramen for the third and fourth cranial nerves, at a somewhat higher level and separated from it by a space of about 27 mm., is an opening of large size, the foramen ovale or trigeminal nerve (V) exit. This foramen occupies its characteristic position in the reptilian skull in front of the proötic. It lies for the most part within the alisphenoid with the proötic bounding it posteriorly, and is a short distance above the hinder end of the base of the flange directed outward from the upper portion of the basisphenoid. Its outer opening is larger than the inner one but its greatest diameter is attained within the thickness of the bone where the size of its passage through is considerably increased by excavation forming a fossa.

This foramen is best preserved on the right side in the paratype of *Edmontosaurus* where externally it is longer than high, subtriangular in outline and highest in front, measuring 24 mm. in length and 18 mm. in height. On the left side of the specimen the opening has been reduced in height by crushing. Leading forward from it anteriorly is an open channel or groove which marks the position of the ophthalmic branch of the trigeminal nerve (V) (see also p. 52). The suture between the alisphenoid and the proötic reaches the opening posteriorly from above.

In the floor of the brain-cavity, midway between and at a slightly lower level than the trigeminal nerve (V) exits, are two small openings,

one on either side of the longitudinal midline of the floor, which mark the origin of the abducent or sixth nerve from the ventral region of the medulla. From each of these openings a long, straight passage leads forward with a downward inclination into the pituitary cavity debouching immediately below the hinder rim of the pituitary fossa, and in close proximity to the foramen for the third and fourth nerves. The two passages are parallel to each other and pierce the basisphenoid in its median elevation behind the pituitary fossa. From the position of the anterior end of these passages it is presumed that the sixth nerve, a purely motor nerve supplying the external rectus muscle of the eye, found exit also from the large aperture apportioned to nerves III and IV.

The foramen for the seventh or facial nerve, behind the foramen ovale, and separated externally from it by a surface of bone measuring about 11 mm. across, is small and inconspicuous. A narrow but well-defined channel leads downward and forward from it toward the deep groove, beneath the flange of the basisphenoid, which terminates below at the lower entrance of the internal carotid artery. This foramen pierces the proötic as in the alligator.

Behind the exit of the seventh nerve, and distant from it externally about 16 mm., is a rather large opening, the fenestra ovalis + the fenestra rotunda, which internally communicates directly inward with the brain cavity by a small oval aperture, the internal auditory meatus, through which the eighth or auditory nerve left the brain and reached the auditory organ by means of its various branches. Rising upward in the thickness of the bone from the passage between the outer opening and the internal meatus is a large space which apparently marks the position of the labyrinth. The semicircular canals are not preserved in the specimen (paratype) nor has it been possible to detect any representation of other parts of the auditory organ. The side wall of the brain-case is thickened inwardly at this position of the labyrinth causing a marked convexity of the surface of the bone in the brain-cavity over a considerable area above the internal auditory meatus. At about the middle of this convex area, at about 10 mm. above the meatus is a small opening, between 2 and 3 mm. wide, connecting the large space within the bone with the brain-cavity.

Four foramina of rather small but nearly equal size occupy a definite sunken area bounded below by the lateral convexity of the occipital condyle, and in front and above by a prominent ridge which latter runs upward from the basi-occipital behind the fenestra ovalis and continues almost horizontally backward to the paroccipital process of the exoccipital. This sunken area is most depressed in front where it ends as an excavation beneath the ridge. Of the four foramina two are close together in front, one above the other, and are overhung by the ridge and partly concealed by it in a lateral view of the skull. Anteriorly the ridge is sharp-edged behind and about 12 mm. broad. The third foramen is at a short distance behind the front pair, and the fourth follows the third at a somewhat increased interval. The lower anterior opening and the two posterior ones are in an almost straight line horizontally. The upper of the two front apertures, slightly larger than the lower one, is the foramen lacerum posterius transmitting the glossopharyngeal (IX), the pneumogastric (X), and the spinal accessory nerves. The direction of the passage outward through the bone for these nerves is obliquely backward. The inner end

of the passage is large and close behind the internal auditory meatus, the external one is much smaller and opens under the ridge already mentioned about 9 mm. distant from the back margin of the fenestra ovalis. The lower opening is for the transmission of the jugular vein. The passage for this vein starts within the wall of the brain-cavity in a small orifice well down in the medullary region some distance beneath the inner end of the foramen lacerum posterius. It curves upward and backward through the bone and emerges close beneath the common exit of the ninth, tenth, and eleventh nerves, separated from it only by a thin partition of bone so that the two openings are almost confluent externally. Near the external end of the jugular passage there seems to be a branch leading forward within the bone, but it is small and its course has not been ascertained. The opening behind the foramen lacerum posterius, and distant from it about 8 mm., is the anterior condyloid foramen, Figures 26 and 27, *a, c, f*. The hindmost of the foramina, about 16 mm. farther back, is the exit of the twelfth or hypoglossal nerve (XII). Its inner end is considerably larger than the outer one.

Brain. (*Figure 27.*)

The brain-cavity of *Edmontosaurus* is long and narrow but relatively much broader across the cerebrum than elsewhere. Its length is slightly less than one-fourth that of the skull, and it is both actually and proportionately longer than the brain-cavity of *Claosaurus annectens* as represented by Marsh's figure of the cast.

In the paratype of *Edmontosaurus* there is little distortion in the cranium and an accurate gelatine cast of the entire brain-cavity was obtained and reproduced in plaster, Figure 27, *A*, *B*, *C*. The cast includes the nerve exits for their full extent outward, giving the diameter, direction, and length of the passages, and the thickness of the walls of the braincase at any particular opening.

The shape of the brain-cavity probably does not give exactly that of the brain itself especially if conditions were at all similar to those found in the Tuatara (*Sphenodon punctatus*) of New Zealand. Dendy[1] has remarked on the great disparity in size in *Sphenodon* between the brain-cavity and the brain, which latter he found to be suspended in the cavity by innumerable strands of connective tissue. It is reasonable to suppose, however, that in dinosaurs the brain conformed in a moderate degree to the shape of the cavity, and this assumption appears to be borne out by the cast in which the various divisions of the brain seem to be fairly represented as regards size and relief. In describing the cast of the brain-cavity of *Edmontosaurus*, therefore, its different parts will be referred to in terms that would be applied to the brain itself.

In Figure 27, the cast is shown in lateral, A, superior, B, and inferior, C, aspects. In it the principal divisions of the brain are denoted, viz., the olfactory lobes, the cerebrum (cerebral hemispheres), the optic lobes, the cerebellum, the medulla oblongata, and the pituitary body. All the cranial nerve exits are represented, as well as the internal carotid artery's entry into the pituitary body from below. Two constrictions are con-

[1]Philos. Trans. Royal Soc. London, Ser. B. vol. 201, 1911, pp. 227-331. "On the structure, development, and morphological interpretation of the pineal organs and adjacent parts of the brain in the Tuatara (*Sphenodon punctatus*," by Arthur Dendy.

spicuous, one behind the cerebrum, the other separating the cerebellum and optic lobes from the medulla.

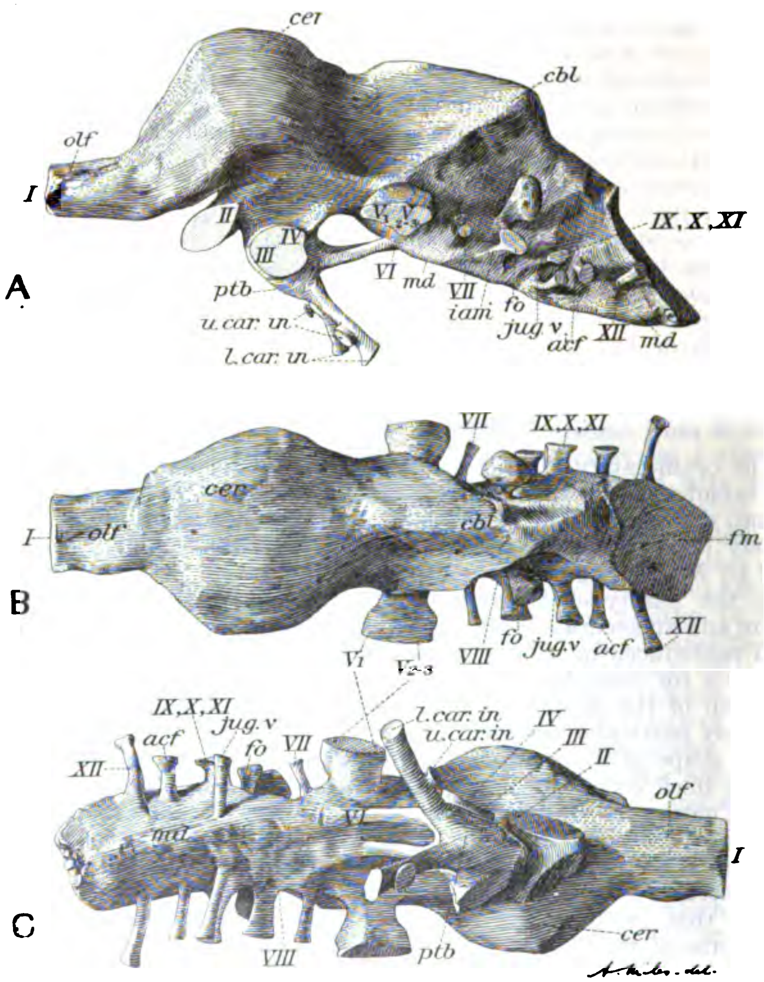


Figure 27. Cast of brain-cavity of Edmontosaurus (paratype, Cat. No. 2289); ½ nat. size. A, left lateral aspect; B, superior aspect; C, inferior aspect; *cbl*, cerebellum; *cer*, cerebrum; *l. car. in*, lower entrance of internal carotid artery; *md*, medulla oblongata; *olf*, olfactory lobes; *opl*, optic lobe; *ptb*, pituitary body; *u. car. in.*, upper entrance of internal carotid artery; *I*, olfactory nerve; *II*, optic nerve; *III*, oculomotor nerve; *IV*, Pathetic or trochlear nerve; *V*, trigeminal nerve; *VI*, abducent nerve; *VII*, facial nerve; *VIII*, auditory nerve; *IX*, glossopharyngeal nerve; *X*, vagus or pneumogastric nerve; *XI*, spinal or accessory nerve; *XII*, hypoglossal nerve.

As seen from the side the upper outline descends rapidly in the front face of the cerebrum to the olfactory lobes where it continues horizontally forward. With the exception of the depression caused by the constriction behind the cerebrum, the superior outline, sloping gently forward, continues

back, but slightly lower in elevation than the cerebrum, to the cerebellum beyond which it has a rapid descent to the foramen magnum. The inferior outline ascends gradually from the floor of the foramen magnum to the forwardly placed pituitary body which depends in line with the posterior part of the cerebrum. The lower outline of the olfactory lobes is horizontal in advance of the backwardly ascending lower surface of the cerebrum.

Viewing the cast from above or below the greatest breadth is across the cerebrum in great contrast to the comparatively slender olfactory lobes, and the less slender but narrow portion extending back from the cerebrum.

The brain of *Edmontosaurus*, relying on the proportions of the cast of the brain-cavity, was about two and a half times as long as its maximum height, i.e., from the lower end of the pituitary body to the level of the upper surface of the cerebrum (cerebral hemispheres). For a little over half its length forward from the foramen magnum it is narrow, angulated above, and constricted on the sides over a considerable area above the auditory nerve. Forward it broadens greatly into the cerebrum and ends narrowly in the olfactory lobes. The cerebellum rising with a steep posterior slope, is laterally compressed, but does not reach as great an elevation as the cerebrum which is the highest part of the brain. The angulation of the upper surface continues forward from the cerebellum and ends at a constriction defining the hinder limit of the cerebrum. A lateral angulation runs obliquely downward and forward from the cerebellum to above the trigeminal nerve apparently marking the posterior boundary of the optic lobe. The constriction just mentioned (posterior commissure) is continued down the sides in advance of the optic lobe between it and the cerebrum (or behind the primary fore-brain or *thalamencephalon* if it were recognizable).

The cerebrum is almost hemispherical in shape, broadly rounded in all directions above, and flatly convex transversely in its anterior surface which descends very rapidly to the olfactory lobes. Laterally where it reaches its greatest breadth it overhangs its flattened lower surface. The infundibulum extends downward in line with the posterior part of the cerebrum (from the primary fore-brain) narrowing below with a backward inclination and terminating in the pituitary body.

The olfactory lobes, not distinguishable as a pair in the cast, are produced horizontally forward and are together much broader than deep; they are transversely somewhat concave above and moderately convex below with a slight median, longitudinal angularity.

The medulla occupies about half the inferior length of the brain, and posteriorly is considerably higher than broad, angulated both above and below, with its greatest diameter at about midheight. Farther forward its sides are sunken, where the walls of the brain-case are thickened in the neighbourhood of the eighth nerve, and its lower surface becomes flattened, retaining, however, a slight transverse convexity.

Measurements of Cast of Brain-cavity of Edmontosaurus (paratype, Cat. No. 2289).

	Mm.
Length, posterior end of floor of foramen magnum to termination of optic lobes....	262
Breadth across cerebrum....	77
Anterior height of olfactory lobes....	15
Anterior breadth of olfactory lobes....	32
Height vertically above lower end of pituitary body....	98

Height in line with trigeminal nerve (V)	74
Breadth at trigeminal nerve	54
Breadth just behind the facial nerve (VII)	35
Height in line with auditory nerve (VIII)	76
Breadth behind auditory nerve	42
Posterior height, from lower surface of medulla, in advance of hypoglossal nerve (XII)	52
Posterior breadth at midheight of medulla	41

Teeth.

Figure 28 shows the manner in which the teeth follow each other in the Hadrosauridæ as a group. The number of vertical series in the dentary and maxillary magazines varies in the different generic forms as also does the number of individual teeth in the vertical series. The

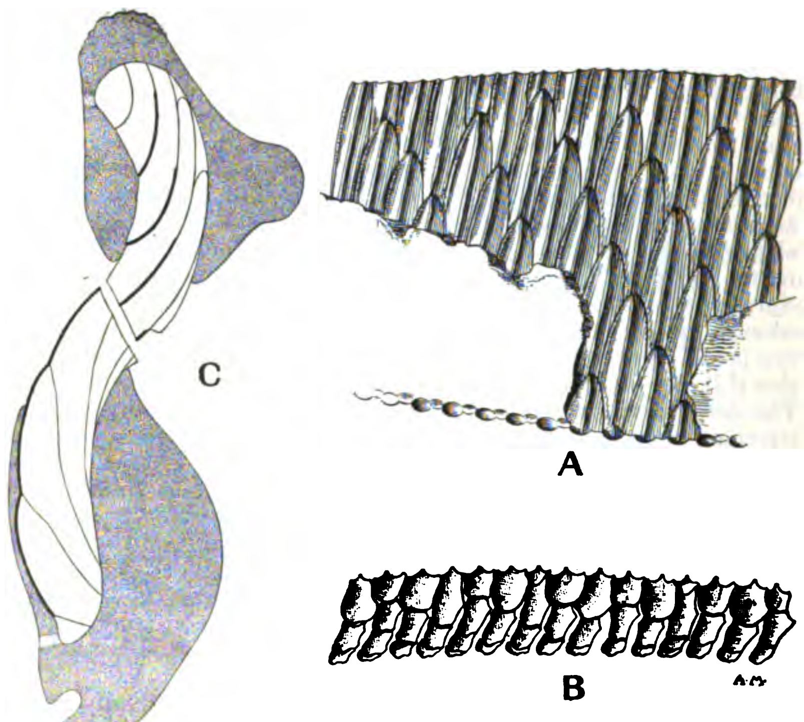


Figure 28. Illustrating the general type of tooth formation and succession in the Hadrosauridæ. A, internal view of vertical series of teeth of lower jaw; B, view from above of teeth of lower jaw worn down by use; C, diagrammatic representation of teeth of both jaws in cross-section. ½ natural size.

large number of teeth in each jaw and their manner of implantation render the dentition remarkably complicated. As the teeth were evidently worn down rapidly a system of continuous replacement was necessary and for this purpose many reserve or successional teeth were provided in vertical series of from five to eight teeth, each tooth in a series overlapping the one which preceded it. The vertical series curved outward in the lower

jaw and inward in the upper one so that the worn surface of the teeth in the two jaws came together with a shearing action in an almost vertical direction. As a result of the curve in the vertical series, and of the overlapping of individual teeth therein, as many as three or even four teeth belonging to a series might be in use at the same time, viz., one worn down to a stump, and one, two, and sometimes three succeeding teeth in progressive stages of wear, providing a tessellated shearing surface of considerable breadth and having a length equal to that of the magazine. The dentary teeth succeed each other in both jaws from the inner side. In the dentary the enamelled face of the crown of the teeth is on the inside providing a continuous enamelled surface to the full extent of the magazine. The maxillary teeth bear enamel on their outer side and for this reason and in consequence of their inward curve the enamelled surfaces in the vertical series of teeth are not brought into juxtaposition after the manner of the mandibular teeth.

The teeth of *Edmontosaurus* conform to the general rules governing tooth implantation and succession in the Hadrosauridæ and are arranged in the usual closely fitting vertical rows of which there are forty-eight or forty-nine in the dentary with four or five teeth and sometimes the stump of a sixth in each row.

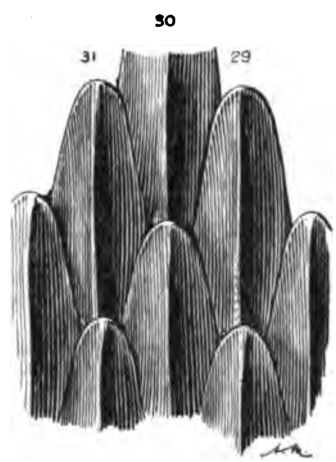


Figure 29. Enamelled face of teeth, in twenty-ninth to thirty-first vertical series from the front, in left dentary of Edmontosaurus, Cat. No. 2289; natural size.

The dentary teeth are largest at the mid-length of the magazine and decrease in size toward either end of it, the posterior ones being considerably shorter but only slightly narrower than those in front. The inner enamelled tooth-surfaces, in lateral aspect, are nearly lozenge-shaped in outline, with the longer diameter vertical, and fit closely together quincuncially in a mosaic which is almost half covered from below by the thin alveolar wall. The enamelled portion of the teeth is evenly rounded above, and emarginated at the narrow base where the apex of the next succeeding tooth closely fits. It bears a high, broad-based, sharp-edged, median keel running its length, between which and the margin on either side, the surface is evenly concave transversely. The succession of keeled teeth from below results in the whole of the inner face of the dentary magazine being regularly fluted in a vertical direction. A slight elevation of the margin is developed in the apical curve of the larger teeth, and is also present, to a varying extent, in the smaller anterior and posterior ones along the sides. In the majority of the dentary teeth the margins are smooth, but in the first five or six vertical rows marginal papillations occur between the tooth's apex and the angulation at its maximum breadth.

Three dentary teeth, of the same vertical series, in progressive stages of wear, are in use in the cutting surface at the same time. This number toward either end of the magazine is generally reduced to two.

In the maxillary magazine there are from fifty-one to fifty-three vertical rows of teeth. The enamelled face of these teeth is narrower than that of the dentary, the median keel is higher in the upper or basal portion of the tooth, the margins toward the apex are more elevated, and, in the smaller teeth at either end, are crossed in an oblique direction by numerous papillose ridges. The outer enamelled faces of the teeth do not combine as on the inner side of the dentary magazine to form a continuous fluted surface but present a rather irregular, longitudinal row of crowns in which the less protrudent or non-functioning teeth are seen, where the roots of the used up teeth have dropped out, deep-set between the functioning ones. The maxillary teeth seem to have been, in the cutting surface, in a single, longitudinal row in successive sequences of three showing a progressive amount of wear. It is possible, however, that in individuals of this genus, two maxillary teeth of the same vertical series may have been in the cutting surface near the mid-length of the magazine at the same time.

The cutting surface of the dentary magazine of teeth met that of the maxillary magazine in a shearing action after the manner of the blades of scissors. In many jaws of hadrosaurs these cutting tooth surfaces are not in an even plane longitudinally but are more or less undulatory as the result of unequal wear of individual teeth. For the same reason an unevenness of the surface in a transverse direction was frequent. The effectiveness of the jaws as shears was dependent on the evenness of the cutting surface of the dental magazines and the frequent occurrence of irregular curvature in these composite dental surfaces can be taken only as evidence of the inefficiency of this particular kind of dentition except for cutting and chopping the softest and most succulent of plants.

Measurements of Teeth of Edmontosaurus, Cat. No. 2289.

	Mm.
Teeth of right dentary:	
Non-functioning tooth of average size of those near the midlength of the magazine—	
Height of inner enamelled surface	34
Maximum breadth of same at midlength	11·5
Breadth at lower end of same	6
Non-functioning tooth from seventh vertical row from the front—	
Height of enamelled surface	26
Breadth of same at midheight	10
Breadth of same at lower end	5
Non-functioning tooth from seventh vertical row from the back—	
Height of enamelled surface	19
Breadth of same at midheight	9
Breadth of same at lower end	4
Teeth of left maxillary:	
Functioning tooth in twenty-fourth vertical row from the front—	
Height of outer enamelled surface	27
Breadth of same at midheight	8·5
Breadth of same at upper (basal) end	7
Functioning tooth in fifth vertical row from the front—	
Height of enamelled surface, about	17
Breadth of same at midheight	7
Functioning tooth in ninth vertical row from the back—	
Height of enamelled surface, about	17
Breadth of same at midheight	7

VERTEBRÆ.

There are available for present description one cervical and three dorsal vertebræ belonging to the 1916 skeleton, Cat. No. 2289. In both skeletons the greater part of the tail is missing, in the type from behind the sixth caudal, in the paratype from behind the fifth, but in each the remainder of the vertebral column is apparently present. Until the enclosing matrix is removed the vertebral column as a whole cannot be described in detail, but the four vertebræ of the paratype so far taken from the rock supply with accuracy the characteristics of the majority of the presacral vertebræ, and indicate the changes in form and proportion that took place in passing back from the head.

There was a general increase in size in the presacral vertebræ in passing back in the series.

The cervicals, and the anterior dorsals at least, were strongly opisthocœlous. Neural spines were absent, or feebly developed in the majority of the cervicals until apparently late in the series. In the dorsals they were short anteriorly in the series but gained slightly in length posteriorly. The transverse processes in the anterior dorsals were long and stout, and pointed upward with an inclination outward and forward. In the posterior dorsals they were almost horizontal, and less robust. The cervical and dorsal ribs with the exception of the last dorsal, or possibly the last two or three, were double headed.

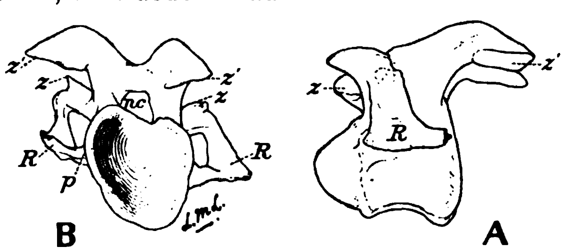


Figure 30. Cervical vertebra of paratype of Edmontosaurus, Cat. No. 2289; ½ natural size. A, left lateral view; B, posterior view. *nc*, neural canal; *ns*, neural spine; *p*, parapopyhsis; *R*, rib; *tp*, transverse process; *z*, prezygapophysis; *z'*, postzygapophysis.

Cervical Vertebra. This vertebra (Figure 30) from the paratype of *Edmontosaurus* is apparently from near the middle of the cervical series. The centrum is deeply cupped behind, and the anterior end is correspondingly convex. It narrows to the front, and has a length considerably in excess of the posterior height and breadth which latter are about equal. The ventral surface is narrow and flat, and angulated laterally where it passes into the excavated sides of the centrum. The anterior face is bounded posteriorly by a definite protruding girdle against which the narrow rim of the concave posterior end of the preceding centrum fitted. The neural arch is lower than broad enclosing a large neural canal. The transverse process is short and stout and is directed obliquely upward and outward horizontally in line with the neural canal; it terminates distally in a facet for the attachment of the tubercle of the rib, and gives off superiorly a short prezygapophysis. Laterally a short parapophysis with a narrow vertical diameter provides for the attachment of the head of the rib considerably below the level of the floor of the neural canal. The posterior zygapophyses are long, robust, and curve backward far beyond the posterior end of the centrum. The articulating surfaces of the post- and prezygapophyses facing downward and upward respectively, are

inclined but slightly from the horizontal. There is no neural spine. The neural arch ends in an angulation above from which two ridges diverge backward, one to each postzygapophysis. With this centrum both ribs are preserved to which reference will be made later.

Measurements of Cervical Vertebra (distorted) of Paratype of Edmontosaurus.

	Mm.
Maximum length, about	175
Maximum height, about	157
Length of centrum	123
Anterior height of same, about	74
Posterior height and breadth of same, about	85
Depth of concavity of posterior end of centrum	38
Diameter of neural canal	37

Anterior Dorsal Vertebra. The dorsal vertebra here described (Figure 31) is from the paratype of *Edmontosaurus* and is the anterior one of two having much the same size and proportions. It appears to be about the fourth or fifth from the front in the dorsal series. Two ribs, one of which is well preserved in its entirety (Figure 33), evidently belong, judging from their proportions, to this particular vertebra.

The centrum of this vertebra is opisthocœlous, but with the concavity and convexity less than in the cervical vertebra above described. It is longer than high, narrows downward, is pinched on the sides, and has a longitudinal keel below between the articulating ends. The neural arch is high and robust. The neural spine is short and does not rise much above the top of the transverse processes. It is broad in the fore-and-aft direction, inclined backward at an angle of about 45 degrees to the horizontal, is thin, and comes to a sharp edge along its anterior slope the base of which is vertically above the midlength of the centrum. It extends far beyond the posterior end of the centrum. It narrows slightly above its midheight, but regains its lower breadth by expanding above at the curved superior border which is thickened and rugose. The transverse processes are long and heavy, and rise upward at an angle of about 35 degrees to the vertical, inclining backward nearly as much as the neural spine. Anteriorly they come to a thin, sharp edge which is a continuation upward, with a change of direction outward of the narrow upper border of the prezygapophyses. Interno-posteriorly a thin flange is developed connecting them with the postzygapophyses. Externo-posteriorly a much stouter flange extends down to the posterior shoulder of the neural arch. Between these flanges a deep excavation leads downward and is separated from the corresponding excavation of the other side by a median lamella of bone extending up from the neural canal and supporting the pair of postzygapophyses from below.

The development of flanges in the transverse processes results in their being subtriangular in outline in cross-section. There is an inner face, broad and flat, an antero-external one becoming transversely concave in its upper part, and a third directed almost backward also concave with the concavity rapidly increasing below. The second and third faces are about equal in extent and both are narrower than the inner face.

The pre- and postzygapophyses, facing in opposite directions, are inclined at an angle of about 55 degrees to the horizontal, or about 70 degrees to each other. Their flat articulating surfaces are oval in outline, with diameters in the proportion of 4 to 7, the shorter diameter being transverse. These surfaces have about the same length as those of the cervical vertebra (Figure 30) but are slightly broader.

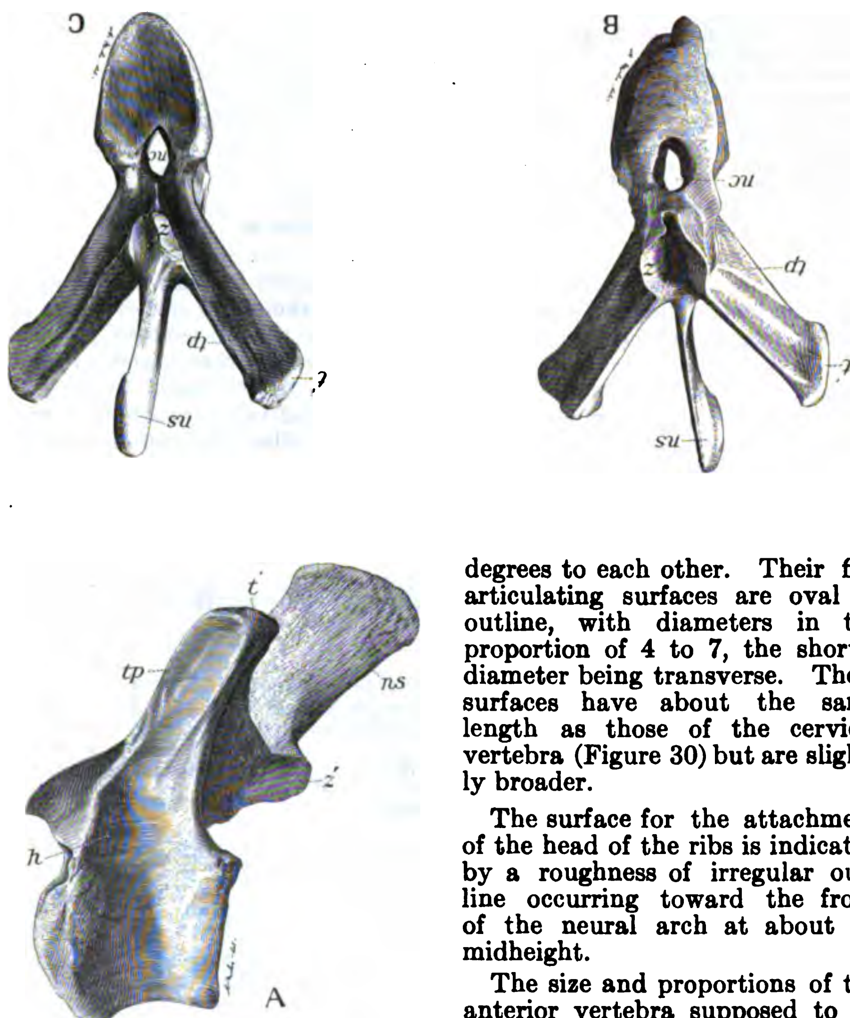


Figure 31. Anterior dorsal (?fifth) vertebra of Edmontosaurus, Cat. No. 2289; ¼ natural size. A, left lateral aspect; B, anterior aspect; C, posterior aspect; *h*, surface for head of rib; *nc*, neural canal; *ns*, neural spine; *t*, surface for tubercle of rib; *tp*, transverse process; *z*, prezygapophysis; *z'*, postzygapophysis.

The surface for the attachment of the head of the ribs is indicated by a roughness of irregular outline occurring toward the front of the neural arch at about its midheight.

The size and proportions of the anterior vertebra supposed to be the fifth or sixth of the series are very similar to the one above described and figured; it is equally well preserved and any special reference to it is not considered necessary.

Measurements of Dorsal Vertebra (?fourth or fifth) of Paratype of Edmontosaurus.

	Mm.
Maximum length	327
Maximum height	352
Length of centrum at midheight	151
Anterior height of centrum, about	97
Posterior height of same	93
Posterior breadth of same	81
Depth of concavity of posterior end of centrum	20
Height of neural canal, about	42
Anterior height of neural spine measured along its slope	194
Antero-posterior breadth of same at upper end	106
Transverse thickness of same at midheight	10
Length of transverse process measured from base of neural spine	128

Posterior Dorsal Vertebra. The vertebra shown in Figure 32 is apparently the last of the dorsal series judging from the small size of the single-headed ribs which are preserved attached to the transverse processes. This vertebra belongs to the paratype of *Edmontosaurus* and gives the changes in form that have resulted in passing to the back of the series. It has much the appearance of an anterior caudal vertebra which it might readily be mistaken for but for the presence of ribs. In comparison with the anterior dorsals there is an increase in size, the centrum is of a different shape, the neural spine is upright instead of sloping backward, and the transverse processes have become almost horizontal.

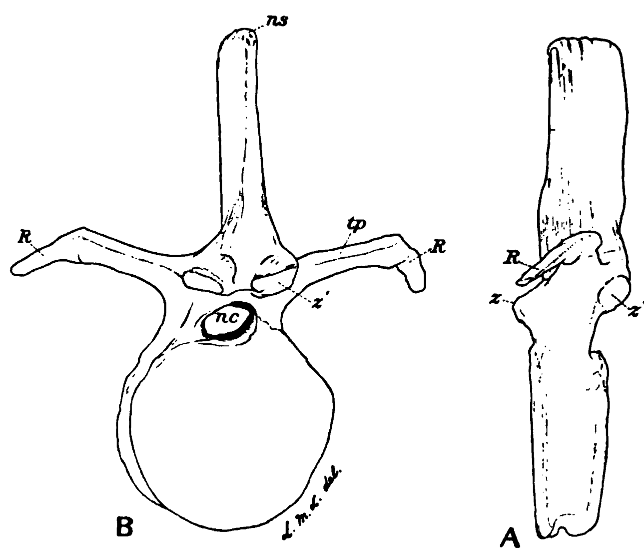


Figure 32. Posterior dorsal vertebra of paratype of Edmontosaurus; ⅛ natural size. A, left lateral aspect; B, posterior aspect. Lettering as in Figures 30 and 31.

The centrum is about as broad as high, and is very short. The posterior end is moderately concave, the anterior one almost flat with a slight convexity. The sides are deeply concave in a fore-and-aft direction, and ventrally a longitudinally directed ridge connects the two ends. In

comparison with the anterior dorsals the neural arch is lower, the neural spine longer, thicker, and not so broad antero-posteriorly.

The articulating surfaces of the zygapophyses are larger than in the anterior dorsals, the difference being principally in the breadth. Their outline is broadly oval, the proportion of breadth to length being about as 4 to 5. They slope at an angle of about 26 degrees to the horizontal and are farther apart than those of the anterior dorsals. The anterior border of the neural spine starts narrowly from between the prezygapophyses and is continued thinly upward to about the midheight of the spine. From each postzygapophysis a short, stout flange proceeds upward to the neural spine as lateral boundaries to a median excavation which becoming shallower in its upward course channels the posterior border of the neural spine to above its midlength.

The transverse processes are shorter than, and slender in comparison with, those of the anterior dorsals, and lack the latter's conspicuous development of flanges. They proceed directly outward from between the pre- and postzygapophyses with only a slight inclination upward. Their strongest connexion below is with the anterior border of the neural arch in the nature of a buttress merging with the prezygapophyses. The outline of their cross-section at midlength is somewhat oval with the greater diameter horizontal, more rounded in front than behind, and more than twice as broad as deep.

Measurements of Posterior Dorsal Vertebra of Paratype of Edmontosaurus.

	Mm.
Maximum height	498
Maximum breadth (distance between outer ends of transverse processes), about	317
Length of centrum	75
Breadth of same	184
Height of same	182
Amount of concavity of posterior end of same	25
Height of neural spine above base of transverse process	220
Antero-posterior breadth of same at midheight	74
Thickness of same at midheight	21
Height of neural canal	41

RIBS.

The ribs of *Edmontosaurus* at present available for description belong to the paratype and consist of the pair in place on the cervical vertebra above described (Figure 30), the pair preserved with the posterior dorsal also already described (Figure 32), and two, presumably a pair, apparently belonging to the anterior dorsal vertebra shown in Figure 31.

Cervical Ribs. The ribs of the cervical vertebra, Figure 30, are double-headed and very short, and consist mainly of a triangular plate of bone, diminishing backward, composed of the shaft and the broad tubercle set in a vertical plane. The neck is given off below from the front of and at right angles to the shaft, its junction with the shaft being sharply angulated externally. The neck is broad antero-posteriorly, and thin, thickening internally for the formation of the head. This latter, connecting with the short parapophysis, is much broader antero-posteriorly, than deep. The posterior portion of the shaft is short, slender, and triangular in cross-section, being flat above, and keeled below by the backward continuation of the angulation at the outer termination of the neck.

Thoracic Ribs. Of the pair of ribs assigned to the anterior dorsal vertebra (?fourth or fifth) the one of the right side is complete and well preserved, the left one is in an equally good state of preservation but lacks a short piece from the lower end.

Figure 33. Right rib of ?fourth or fifth dorsal vertebra of paratype of Edmontosaurus; anterior view obliquely from without; ⅛ natural size. *h*, head; t, tubercle.

These anterior ribs (Figure 33) are long and strongly built with a moderately curved, tapering body or shaft, a well-developed head and tubercle, and a deep, thin neck. In the upper half of the shaft the bone is thick with a rounded border along the antero-internal curve and down to the head; along the postero-external curve and between the tubercle and the head it comes to a rather thin edge. The broadest part of the rib is below the tubercle. The posterior face in the upper half of the shaft, and for a short distance past the tubercle toward the inner border of the neck, is transversely concave. For a corresponding distance on the anterior face the surface is transversely convex, the convexity developing down the shaft into a well-defined median ridge which merges farther down into the antero-internal border. It is along this ridge that the bone is thickest. In the lower half of the shaft the bone becomes more nearly ovate in cross-section being somewhat thicker near the outer curve with the greatest diameter directed externo-internally. Along this lower portion of the shaft the rate of taper is lessened. At the extreme lower end the bone thickens and there is a roughened surface for the attachment of the costal cartilage. The neck is directed downward, inward, and slightly forward at an angle of about 110 degrees to the upper part of the shaft.

The head of the rib is set rather squarely across the neck and expands to a thickness which is twice that of the neck near its lower border. Its articular surface is undulating, pitted, and rugose with an irregular lengthened oval outline about twice as deep as broad.

The tubercle is prominent but much smaller than the head. Its articular surface is about half that of the head in area and is set at much the same angle. From the point of view at which the rib has been drawn neither of these articulating surfaces is fully seen in Figure 33.

Measurements of Right Thoracic Rib (?fourth or fifth) of Paratype of Edmontosaurus.

	Mm.
Length along antero-internal curve from the head to the lower end (about 53½ inches)	1,360
Distance from upper end of tubercular facet to top of head	180
Depth from top of tubercle to inner curve	140
Depth of neck at about its midlength	75
Thickness near lower border of same	17
Height of capitular facet	74
Breadth of same	35
Height of tubercular facet	45
Breadth of same	28
Greater diameter of lower extremity	41
Lesser diameter of same	24
Greater diameter of rib at midlength	42
Lesser diameter at midlength	21

The ribs attached to the large posterior dorsal vertebra (Figure 32) are very short with a length of only about 85 mm. They decrease in diameter rapidly for one-third of their length outward from the transverse process and then retain much the same size for the remainder of their length. They are vertically compressed with the greater diameter equal to about twice the lesser one. They incline a little forward and have the upper surface directed slightly to the front.

Fore Limb.

Humerus. The humerus of *Edmontosaurus* is a robust bone slightly over four times as long as its upper transverse breadth. The radial crest is very strongly developed and is the most conspicuous feature of the bone giving to it in its upper half the great breadth common to the humeri of the Hadrosauridæ.

In the right humerus, Figure 34, of the paratype of *Edmontosaurus*, the shaft is somewhat sigmoid in its length bending backward in its upper half and to about the same extent forward below. The head is rather small and occupies a central posterior position superiorly overhanging the shaft. It is supported beneath by a strong buttress, with a rounded border, passing below into the posterior face of the shaft. It is roughened on the upper and hinder portions of its convexity, is deeper than broad, and forms the highest part of the upper surface of the bone. The inner and outer tuberosities extend outward on either side of, and at a lower level than, the head with a forward curvature which renders the anterior face of the bone above concave. Of the two tuberosities the internal one is the stouter. The radial crest extends downward on the shaft from the outer tuberosity as a comparatively thin flange to below the midheight of the bone. It keeps about the same breadth downward before it suddenly narrows and becoming increasingly thicker merges into the shaft. From the inner tuberosity an obtusely angulated ridge extends down the shaft with decreasing prominence to below the level of the radial crest. The shaft below the radial crest is thick and strong with a somewhat ovate outline in cross-section, the greatest thickness being anterior and slightly external. The lower extremity narrows slightly backward and is flattened on the sides. The condyles are well rounded below, narrow transversely,

and protrudent in front. The inner one is the larger of the two and thicker both in front and behind. Its fore-and-aft diameter is equal to the maximum combined condylar breadth. The condyles are separated below by a deep groove which behind continues up between them to the shaft and in front widens into a large concavity. Posteriorly on the shaft, toward the inner side, at about one-third of the bone's length from the top, there

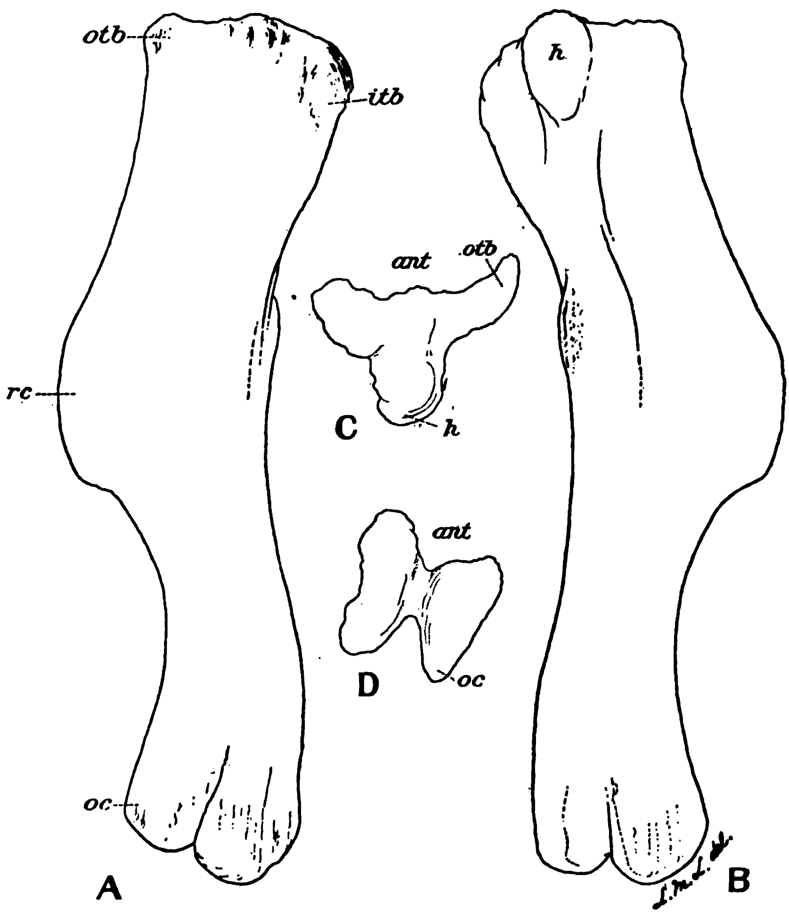


Figure 34. Right humerus of paratype of Edmontosaurus; $\frac{1}{3}$ natural size. A, anterior aspect; B, posterior aspect; C, outline of proximal end; D, outline of distal end; *ant*, anterior; *h*, head; *itb*; inner tuberosity; *oc*, outer condyle; *otb*, outer tuberosity; *rc*, radial (deltoid) crest.

is a prominent, roughened, vertical ridge for muscular attachment. Also the lateral surfaces of the distal end of the bone, and the border, and external face, of the radial crest in its lower part are coarsely striated for muscles. As the radial crest is directed obliquely outward and forward it is foreshortened when viewed as in Figure 34, A and B, and appears narrower than it really is.

Measurements of Right Humerus of Edmontosaurus, Cat. No. 2289.

	Mm.
Length	694
Maximum transverse breadth at proximal end	167
Distance from lower angulation of radial crest to posterior face of shaft	165
Thickness of radial crest at its midlength and breadth	21
Thickness of same at a short distance in from its lower angulation	36
Antero-posterior diameter of shaft at one-third of the bone's length from distal end	92
Interno-external diameter at same level	70
Maximum transverse breadth of distal end	116
Antero-posterior diameter of inner condyle	114
Antero-posterior diameter of outer condyle	104

Ulna (*U.*). *Figure 35.* The ulna is the longest bone of the fore limb, the humerus being the next in length, with the radius slightly shorter than the humerus. The ulna exceeds the radius in length by about 95 mm. It is slender for its length, is heaviest in its upper half, and reaches its maximum size proximally. Distally it is only slightly enlarged. At its upper end its outline in cross-section is triangular. Here the olecranon process is well developed rising to a considerable height above the articular surface for the humerus. Anteriorly toward the inner side above it is excavated for the proximal end of the radius, the excavation narrowing and lessening downward, and disappearing above the bone's half-length. Below the olecranon process posteriorly there is a protrudent angulation which accentuates the general forward bend of the bone in its upper part. At midheight the shaft is oval in cross-section, with the greater diameter fore-and-aft, and one and a half times the lesser diameter. Distally the greatest diameter is nearly twice the maximum transverse breadth, and on the inner side toward the front there is a rugosely striated, depressed surface for the close application of the distal end of the radius. Throughout, the lower end of the ulna is deeply striated in a longitudinal direction for the insertion of muscles.

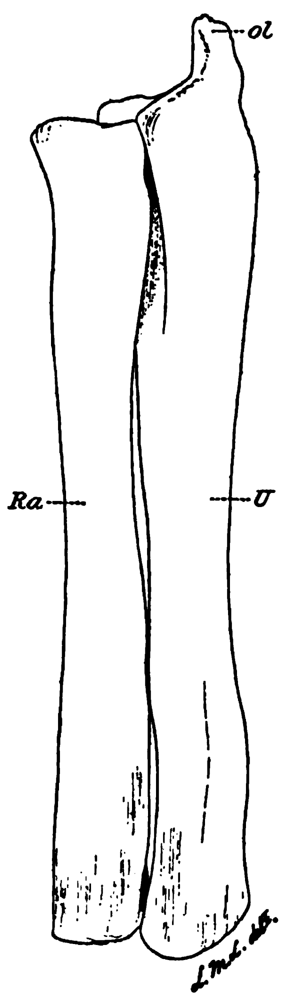


Figure 35. Left ulna and radius of paratype of Edmontosaurus; ¼ natural size; anterior view slightly from without. *ol*, olecranon process; *Ra*, radius; *U*, ulna

Measurements of Left Ulna of Paratype of Edmontosaurus.

	Mm.
Length	760
Maximum transverse breadth of proximal end	128
Maximum diameter of distal end	114
Maximum diameter at midlength	80

Radius (*Ra.*). The radius, Figure 35, is slender, nearly straight, and shorter than the ulna, with a length equal to about 6⅔ times its

maximum thickness proximally. Both ends are enlarged, the proximal one more than the distal one. In comparison with the ulna, the radius is more slender throughout, with less disparity in the size of the ends. At midheight the shaft has an elliptical outline in cross-section as in the ulna but smaller, the diameters in the two bones being in about the proportion of 4 to 5. The outline of the proximal end in superior aspect is nearly square with the greater diameter transverse and the outer and posterior sides fitting into the angular excavation of the ulna. The increase in the size of the proximal end is rapid on the inner and hinder faces, particularly on the latter. Externo-anteriorly for some distance below the upper end the bone narrows outwardly forming a vertical ridge, most protrudent above, which is rugosely striated in the direction of its length and is in close contact, when the bone is in position, with the ulna. The lower end is angulated internally and thickens toward the outer side where it is applied to the ulna. On all sides it is longitudinally striated deeply for muscular attachment. Similar striations are conspicuous also at the upper end.

Measurements of Left Radius of Paratype of Edmontosaurus.

	Mm.
Length	665
Maximum transverse breadth of proximal end	98
Maximum diameter of distal end	87
Maximum diameter at midlength	65

THE GENUS *EDMONTOSAURUS.*

The orthopod genus Edmontosaurus of the family Hadrosauridæ, subfamily *Hadrosaurinæ* (p. 68) represented by the single species *E. regalis*, Lambe, has the following characters:

Generic and Specific Characters. Skull moderately elongate, high and broad posteriorly, flat in the frontal region, laterally compressed behind a low, greatly expanded snout. Orbit large. A large pocket-like recess developed within the postfrontal, leading from the orbit. Lateral temporal fossa restricted above. Palatine and pterygoid rising, at a high angle, inward. Ectopterygoid external to the maxillary and pterygoid, connecting the two. Mandible deep and strong, very slightly decurved in front. Teeth with a rounded apical outline in lateral aspect, keeled, and with smooth borders; in 48-49 vertical rows in the dentary, and 51-53 in the maxillary. Ischium long, bluntly pointed distally. Femur slightly longer than the tibia. Humerus nearly as long as the ulna. Cervical and dorsal vertebræ opisthocœlous, in a marked degree in the former. Dorsal spines of moderate size, increasing slightly in height backward in the series. Sacrum composed of eight vertebræ. Animal of robust build, between 30 and 40 feet long.

Edmontosaurus approaches most closely *Diclonius* Cope of later geological age, one of the principal characters distinguishing the two being found in the general shape of the skull which in *Edmontosaurus* is high and in *Diclonius* greatly depressed. The name *Diclonius*, as used here, is reserved for *D. mirabilis*, Cope, from the Lance formation of Dakota, sometimes referred to as *Trachodon mirabilis* a genus and species insecurely established by Leidy in 1856, on the tooth from the Judith River beds of

Montana. No characters can at present be assigned to Trachodon beyond those derived from the single mandibular tooth which constitutes the type.[1]

Edmontosaurus rivalled in size its bulky contemporary *Hypacrosaurus*. It appears, however, not to have been as large as *Prosaurolophus*, from the Belly River formation of Alberta, if the skull in the Hadrosauridæ can be considered a criterion of the size of the animal as a whole.

CLASSIFICATION OF THE HADROSAURIDÆ.

DIVISION INTO THREE SUBFAMILIES.

The discovery in recent years of many new generic forms of Hadrosauridæ in the western Cretaceous of this continent, more especially in the Belly River and Edmonton formations of Alberta, has greatly enlarged the list of known genera of these herbivorous dinosaurs, and has been the means of increasing our knowledge of their osteology. As a result of the study of these forms it is apparent that three principal groups or subfamilies are represented.

In 1914[2] a classification of the Hadrosauridæ (Trachodontidæ) was proposed by Mr. Barnum Brown who recognized two subfamilies, viz., the *Trachodontinæ* and the *Saurolophinæ*. Since then, principally through the discovery (1915) and further study of *Cheneosaurus*, the discovery in 1917 of a nearly perfect skull of *Stephanosaurus*, and the additional study of the family as a whole, greatly assisted by the well-preserved specimens in the collections of the Geological Survey, it has become evident that certain forms included in the *Saurolophinæ* differ from the *Saurolophus* type in so many fundamental particulars that their withdrawal to form a new subfamily is necessary. For this third subfamily of the Hadrosauridæ the name *Stephanosaurinæ* is proposed, to include the genera *Stephanosaurus* Lambe, *Corythosaurus* Brown, *Cheneosaurus* Lambe, and probably *Hypacrosaurus* Brown. Under the proposed new classification the *Saurolophinæ* are represented by *Prosaurolophus* Brown, and *Saurolophus* Brown. The *Hadrosaurinæ* (*Trachodontinæ* Brown) embrace *Gryposaurus* Lambe, *Kritosaurus* Brown, *Edmontosaurus* Lambe, "*Claosaurus*" Marsh, and *Diclonius* Cope.

The characters denoting the resemblances and dissimilarities of the three subfamilies, as provided principally by the skull, are as follows:

[1] "On the genus Trachodon of Leidy," by L. M. Lambe, Ottawa Naturalist, vol. XXXI, No. 11, February, 1918.

[2] Bull. Am. Mus. Nat. Hist., New York, U.S.A., vol. XXXIII, art. XXXV.

Hadrosauridæ.

Subfamily *Hadrosaurinæ*	Subfamily *Saurolophinæ*	Subfamily *Stephanosaurinæ*
Forms large.	Forms large.	Forms of variable size.
Posterior height of skull variable.	Skull high posteriorly.	Skull high: relatively short.
Supraorbital region flat.	Supraorbital crest developed.	Supraorbital region elevated into hood, or dome.
Fronto-parietal area enlarged.	Fronto-parietal area moderately large.	Fronto-. parietal area reduced.
Nasals extending far forward.	Nasals extending far forward.	Nasals receded.
Anterior nares transversely confluent.	Anterior nares transversely confluent.	Anterior nares separated by premaxillaries.
Nasal passages anteriorly not enclosed in bone.	Nasal passages anteriorly not enclosed in bone.	Nasal passages enclosed by premaxillaries, and greatly enlarged in supraorbital region.
Premaxillaries confined to an anterior position.	Premaxillaries confined to an anterior position.	Premaxillaries prolonged backward and entering largely into formation of hood or dome.
Lachrymal of moderate size.	Lachrymal large.	Lachrymal reduced.
Ischium pointed distally.	Ischium expanded distally.	Ischium expanded distally.
Genera: *Gryposaurus*. Belly River formation. *Kritosaurus*. Ojo Alamo beds of New Mexico = ?*Edmonton* formation. *Edmontosaurus*. Edmonton formation. "*Claosaurus*". Lance formation. *Diclonius*. Lance formation.	Genera: *Prosaurolophus*. Belly River formation. *Saurolophus*. Edmonton formation.	Genera: *Stephanosaurus*. Belly River formation. *Corythosaurus*. Belly River formation. *Cheneosaurus*. Edmonton formation. ?*Hypacrosaurus*. Edmonton formatio

From the above comparison of the subfamilies of the Hadrosauridæ it is apparent that the *Hadrosaurinæ* and the *Saurolophinæ* show a closer approach to each other than to the *Stephanosaurinæ*. These last stand apart with very marked and striking characteristics in about an equal degree from both the others. In them there is a supraorbital enlargement of the skull due to the surprisingly great development and backward extension of the premaxillaries and nasals. In the *Saurolophinæ* instead of a general superior enlargement of the skull there is a crest over the eyes, formed by the nasals in *Prosaurolophus*, and, according to Brown, by the nasals, prefrontals, and frontals in *Saurolophus*.

The only one of the above listed characters common to the *Saurolophinæ* and the *Stephanosaurinæ* is the distal expansion of the ischium. It was this "footed" form of ischium, discovered by the writer in 1898, and first described by him in 1902[1], in connexion with his original description of *Trachodon* (*Stephanosaurus*) *marginatus*, and not until then known in association with any type of orthopod (predentate) dinosaur, that was considered by Hatcher to belong to "some member of the Theropoda"

[1]Contributions to Canadian Palæontology, vol. III (quarto), pt. II.

as expressed in his "Geology and palæontology of the Judith River beds," 1905, p. 97.[1] This author in the writer's opinion also erred in his remarks[2], under the same heading in his report, on the material on which *S. marginatus* was established, as further work on the rich dinosaurian fauna of the Belly River beds of Alberta has so fully proved.

The members of the *Hadrosaurinæ* and *Saurolophinæ* resemble each other in having an elongated narial vacuity, opening through the skull, enclosed above by the nasals and premaxillaries. In both subfamilies there is a forward extension of the nasals, and a limitation of the premaxillaries to an anterior position in the skull. They differ from each other in the absence in the first and the presence in the other of a "foot" or distal expansion in the ischium.

The three subfamilies show distinctive characters in the relative size of the parieto-frontal region, and of the lachrymal.

The *Stephanosaurinæ* are characterized by an extremely high skull in marked contrast to the relatively low skull of the *Hadrosaurinæ* and *Saurolophinæ*, the extreme of skull depression being reached in the *Hadrosaurinæ*, viz., in the genus *Diclonius*. The primary characters of the *Stephanosaurinæ* separating it from the other two are—(1) the envelopment of the anterior nares in, and their separation by, the premaxillaries, (2) the extreme backward extension of the premaxillaries and their enclosure of the narial passages, (3) the enlargement of each narial passage posteriorly, within the supraorbital hood or dome, into an extensive air-chamber bounded by the premaxillaries and nasals.

In these subfamilies the appendicular skeleton and that of the trunk provide also characters which no doubt can be relied on as being distinctive in each.

The *Stephanosaurinæ* were more highly specialized than either the *Hadrosaurinæ* or the *Saurolophinæ*. The arrangement of the elements enclosing the anterior nares and narial passages implies different habits and may indicate a better adaptation to an aquatic life.

The earliest member of the *Hadrosaurinæ* is *Gryposaurus* from the Belly River formation of Alberta represented in Figure 36A by the skull of *G. notabilis* remarkable for its completeness and wonderful state of preservation.

The second genus of this subfamily, viz., *Kritosaurus*, from a not definitely determined geological horizon in New Mexico (the Ojo Alamo beds of San Juan county=?Edmonton formation of Alberta) is noteworthy for the great posterior height of the skull. The radical differences between *Gryposaurus* and *Kritosaurus*, particularly those conspicuously seen in the shape and size of the predentary and the proportionate length of the quadrate, make it probable that further fundamental dissimilarities will be revealed in the skull and other parts of the skeleton when the osteology of *Kritosaurus* is better known.

The type of *Kritosaurus* consists in general terms of the hinder half of the cranium, and a complete mandible, which latter reveals the length of the skull (Figure 36B). The orbital rim, including the postorbital bar, is, in the mounted skull, mostly restored in plaster, and all the facial

[1] "Geology and palæontology of the Judith River beds", by T. W. Stanton and J. B. Hatcher, with a chapter on the fossil plants by F. H. Knowlton; Bull. No. 257, U.S. Geol. Surv.

[2] Cited by C. F. Bowen in "The stratigraphy of the Montana group, with special reference to the position and age of the Judith River formation in north-central Montana", Prof. Paper 90, U.S. Geol. Surv., 1914.

elements in advance of the orbit, with the exception of the maxillary, have also been restored, providing a rather remarkable nasal and premaxillary contour. The maxillary appears to be preserved to near its lower anterior extremity.

Figure 36. Skulls of Hadrosaurinæ. A, Gryposaurus, Lambe; B, Kritosaurus, Brown. $\frac{1}{16}$ natural size.

Edmontosaurus, "*Claosaurus*" *annectens*, and *Diclonius*, Figures 37C, D, and E, respectively, the remaining members of the *Hadrosaurinæ*, illustrate well the general tendency in the crestless forms to a lowering of the skull as time progressed.

Figure 38F is of a skull of *Prosaurolophus maximus* Brown, obtained by C. M. Sternberg of the Geological Survey vertebrate palæontological party of 1914 from beds of the Belly River formation on Red Deer river,

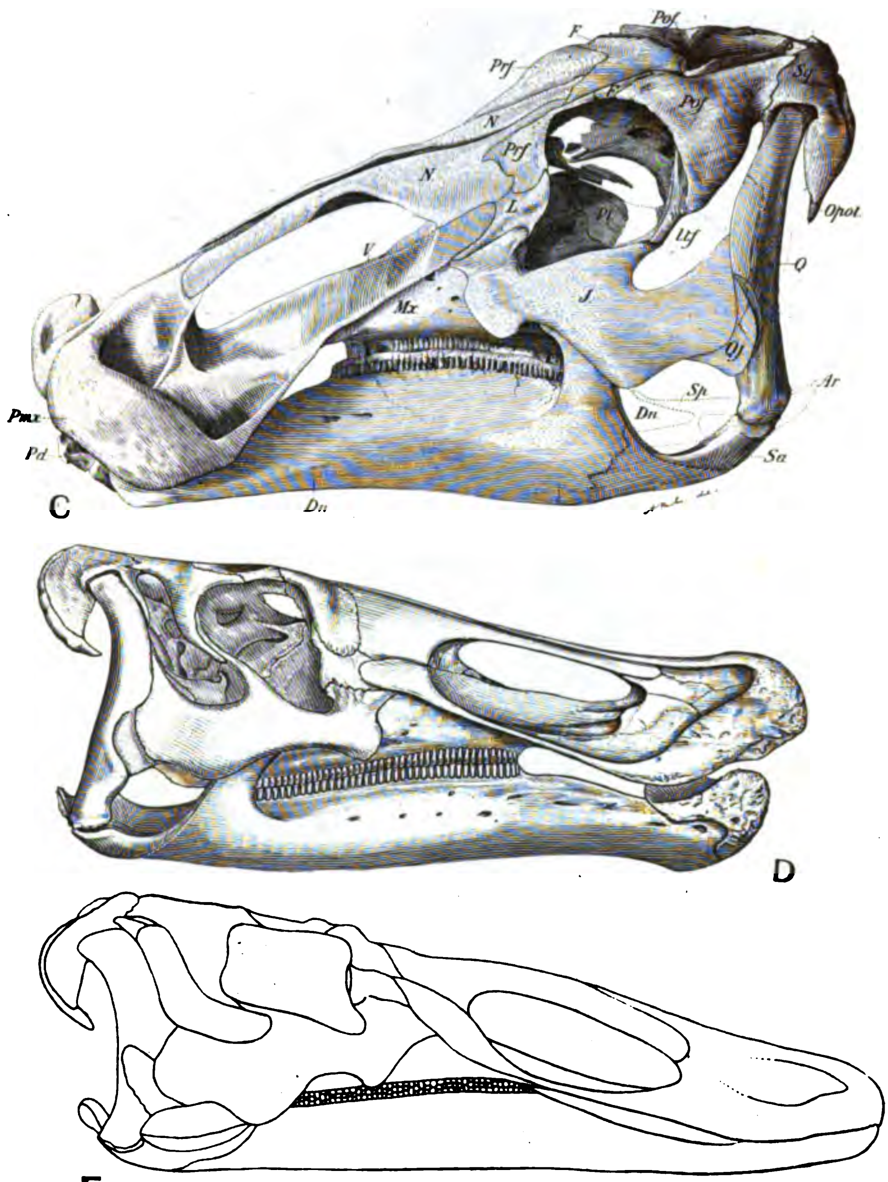
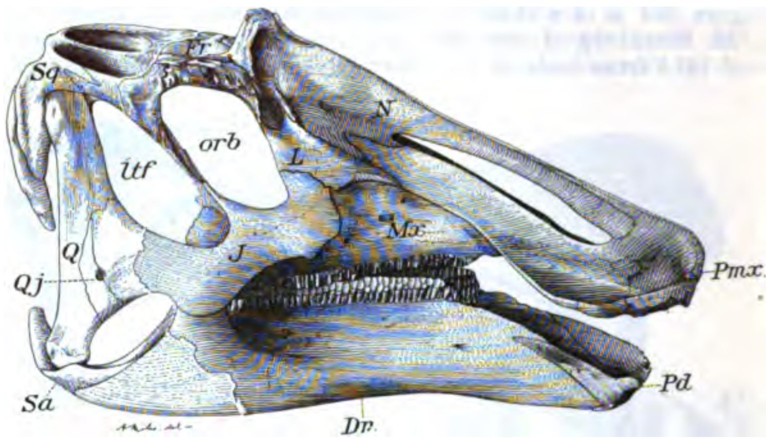


Figure 37. Skulls of Hadrosaurinæ. C, Edmontosaurus, Lambe; D, "Claosaurus," Marsh; E, Diclonius, Cope. $\frac{1}{10}$ natural size.



F

G

Figure 38. Skulls of Saurolophinæ. F, Prosaurolophus, Brown; G, Saurolophus, Brown, 1/8 natural size.

Figure 39. Skulls of Stephanosaurinæ. H, Stephanosaurus, Lambe; I, Corythosaurus, Brown; J, Cheneosaurus, Lambe. $\frac{1}{8}$ natural size.

2 miles east of the mouth of Little Sandhill creek. The specimen consists of all the cranium and mandible in advance of a line passing irregularly down from the front end of the supratemporal fossæ, and supplies the shape of the mandible, and the true length of the snout which is apparently restored to too great a length in the genotype described by Brown in 1916.[1] In the Geological Survey skull the premaxillary and nasal bones are complete and give the proper extent and manner of union of the nasal anteriorly with the upper limb of the premaxillary, the true outline of the posterior termination of the lower limb of the premaxillary, and the position and shape of the posterior end of the nasals. Both the upper and lower teeth are well preserved. The specimen proves that in *Prosaurolophus* the "crest" is formed entirely from the nasals and not chiefly from the frontals as supposed by Brown. In Figure 38F the posterior end of the skull is restored from Brown's figure of the genotype. The skull of *Prosaurolophus* is thus seen to be much shorter than originally described and more in accord with the outline of *Saurolophus* Brown, from the Edmonton formation.

A great advance was made in our knowledge of the structure of the skull of *Stephanosaurus* by the discovery in 1917 in the Belly River formation, Red Deer river, of a skull of *S. marginatus* much more complete and better preserved than the one described by the writer in 1914.[2] In the 1917 specimen (Figure 39H) the extraordinary contour of the head is fully given, and as most of the sutures are traceable, the boundaries of the various elements are revealed, clearing up points of doubt as regards the determination of the bones not only in *Stephanosaurus* but also in *Corythosaurus* and *Cheneosaurus*, other known members of the subfamily.

In the *Stephanosaurinæ* the premaxillaries are greatly extended and enlarged posteriorly relegating the nasals to a position surprisingly far back in the skull.

In *Stephanosaurus* the top of the skull bears a high hood or crest, narrow from front to back, and laterally compressed, from whose posterior base there is a comparatively slender backward prolongation forming a process which reaches far beyond the occiput at a considerable distance above the level of the parieto-squamosal bar. The crest with its posterior extension is made up of the premaxillary and nasal bones. The inferior portion of the premaxillaries is greatly expanded posteriorly to form the central, lower part of the crest proper on either side. Superiorly the premaxillaries form the whole of the crest above, rising vertically in front and descending as steeply behind, thence continuing backward to take part in the formation of the posterior process. The nasals extend obliquely upward and forward from in advance of the small frontals and appear externally in the crest between the broad hinder termination of the inferior part of the premaxillaries (which cannot properly be referred to as a *owerl limb* of the premaxillary) and the posterior descending portion of the premaxillaries above. They also extend narrowly backward beyond the frontals as part of the crest prolongation constituting the lower surface of the process, embracing the premaxillaries from below, and more posteriorly enveloping them externally also. In the back part of the crest, therefore, and in the crest-prolongation, the premaxillaries are between

[1] Bull. Am. Mus. Nat. Hist., vol. XXXV, pp. 701-708, figs 1 and 3.
[2] The Ottawa Naturalist, vol. XXVIII, pp. 17-20, plate I.

the nasals, that is along the whole of the latter's length. A long, narrow vacuity in the crest occurs between the nasals and the lower premaxillary expansion.

A broad, shallow groove runs obliquely upward and slightly backward across the lower portion of the premaxillary a short distance in advance of the anterior end of the jugal. This groove was considered to mark the back termination of the lower part of the premaxillary ("lower limb of the premaxilla") in the original description of the skull of *Stephanosaurus*. What was then named prefrontal is now clearly seen to be the greatly expanded postero-inferior part of the premaxillary as the structure of the bone is continuous across the groove. The prefrontal is small and assists in the formation of the orbital rim between the lachrymal and the postfrontal. The small frontal is excluded from the orbital rim by the prefrontal and postfrontal, and is well under the anterior, lower surface of the naso-premaxillary process.

In the light of our increased knowledge of the structure of the skull of *Stephanosaurus* the original description of the skull of *Corythosaurus* Brown can be amended in certain particulars. What was called prefrontal (Figure 39I) is now clearly seen to be premaxillary. The bone above the orbit determined by Brown as frontal is prefrontal. The frontal is small, as in *Stephanosaurus*, and is hidden beneath the crest. What is named frontal above the postfrontal and squamosal and forming the lower, hinder border of the crest is nasal. The front part of the crest is not nasal but the prolongation upward of the premaxillary. If the suture in the anterior part of the crest in Brown's figure of *Corythosaurus*, marking the back termination of the nasal (premaxillary) be correct then the whole of the crest above the narrow central vacuity may be nasal. If this line be not a suture then the premaxillaries form the upper part of the crest somewhat as in *Stephanosaurus*.

In the *Stephanosaurinæ* the premaxillaries separate the external nares and nasal passages, the latter being enclosed outwardly by an upward growth of the floor of the passage and a downward bend of the roof of the same.

In *Stephanosaurus* the nasal passages lead up into the front part of a large double chamber within the crest, the entry being made at about the midheight of the chamber on either side of a vertical median septum. This nasal chamber occupies the greater part of the crest within, is flanked outwardly by the premaxillary and nasal bones and is somewhat over 150 mm. in height, and narrow from side to side, with a fore-and-aft diameter about three-fifths the height. An exit from the chamber is present below posteriorly leading downward. The position of the chamber is indicated externally by the greater convexity of the crest laterally in an area surrounding the narrow central vacuity. The Stephanosaurinid form of the external nares of *Corythosaurus* and *Cheneosaurus* point to the presence of a nasal chamber in these genera also.

It may be stated here that the determination of the nasal bone in *Stephanosaurus* rests not only on the evidence of the skull shown in Figure 39H, but also on that of fragmentary stephanosaurinid crania in which the sutural surfaces for the nasals are preserved in complete frontals

In the brain-case of the skull of *Stephanosaurus* (Figure 39H) the sutures can be readily traced between the presphenoid and orbitosphenoid, and between the orbitosphenoid and alisphenoid. Also the suture between

the alisphenoid and the basisphenoid is preserved, proving by its position that the large flange, directed outward from above and somewhat behind the basisphenoid process, belongs to and is part of the basisphenoid. It may be of interest also to note that in this skull the ophthalmic branch of the trigeminal nerve (V) is enclosed in bone in its forward course and does not occupy an open channel as it appears to do in *Edmontosaurus*. Further, indicating an unusually perfect preservation of structural detail, the separation of the fenestra rotunda from the fenestra ovalis by a horizontal bar of bone is excellently shown.

To the preparation of this skull by C. M. Sternberg, its discoverer in the field, are due many details of structure that less skilful and painstaking work would not have revealed.

With a better understanding of the stephanosaurinid skull certain errors in the description of the skull of *Cheneosaurus* (Figure 39J) as it appeared in the pages of the Ottawa Naturalist in 1917, can now be rectified. What was regarded as prefrontal is certainly the expanded prolongation backward of the lower, external part of the premaxilla, and the supposed sutural line running forward from the lower end of the lachrymal (see original figure) is evidently a fracture in the bone. The convex, upper surface of the dome is nasal met in front by the upper part of the premaxillary roofing the nasal passage. The bone above the orbit called supraorbital in the first instance is the prefrontal, and the frontal is similar to the frontal in both *Stephanosaurus* and *Corythosaurus* in being small and excluded from the orbital rim by the intervention of the prefrontal and postfrontal.

The posterior height of the skull shows a marked difference in five genera of crestless or flat-headed hadrosaurs (*Hadrosaurinæ*) from the Cretaceous of the west of this continent, viz., in *Kritosaurus* (horizon uncertain = ?Edmonton formation), in *Edmontosaurus* (Edmonton formation), in *Gryposaurus* (Belly River formation), and in "*Claosaurus*" (*annectens*) and *Diclonius* both from the Lance formation. In *Kritosaurus* Brown, from the Ojo Alamo beds of New Mexico, the quadrate is of remarkable length, in *Diclonius* Cope, from Dakota, it is singularly short, the two representing the extremes of skull elevation and depression in the *Hadrosaurinæ* (*Trachodontinæ* of Brown). In these five genera, in all of which, with the exception of *Kritosaurus*, the skull is fully known from excellent material, the proportionate lengths of the quadrate and skull may be expressed in numbers as follows: *Kritosaurus* 1—over 2; *Gryposaurus* 1—2½; *Edmontosaurus* 1—over 2½; "*Claosaurus*" 1—nearly 3; and *Diclonius* 1—nearly 4. From this comparison it is seen that in *Kritosaurus* the posterior height of the skull (length of quadrate) relative to the horizontal length of the same is the greatest, that *Kritosaurus*, *Gryposaurus*, *Edmontosaurus*, and "*Claosaurus*" form a series, in the order named, in which the quadrate is successively reduced in length in about the same ratio, and that the greatest difference in the height of the skull is found between "*Claosaurus*" and *Diclonius*. It would appear, therefore, that as time progressed the skull in the *Hadrosaurinæ*, as a general rule, became lower, culminating in the greatly depressed and very long skull of *Diclonius* in the closing days of the Cretaceous. The posterior height of the skull in *Edmontosaurus* is greater than the average among the genera of flat-headed hadrosaurs in which the head is known.

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